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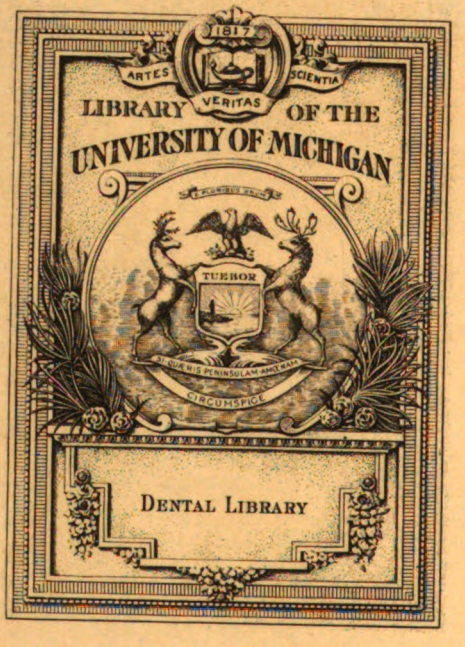
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ROENTGENOGRAPHIC TECHNIQUE

A MANUAL FOR PHYSICIANS, STUDENTS, AND TECHNICIANS

BY

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PREFACE.

INFORMATION obtained from Roentgen-ray examinations is becoming increasingly important in the practice of medicine. The simplification and perfection of Roentgen-ray apparatus has made such information available, in a measure, to every physician living in a community supplied with the necessary electric power.

Every roentgenographic examination consists of two steps—the exposure and development of the films, and their interpretation after they have been made. Many excellent general books and monographs have been published on interpretation. In them a discussion of the technical problems involved in the production of the films is either omitted or given in a general way. All books on roentgenographic technique are either obsolescent or incomplete in some particular. For these reasons it is believed that there is a need for a book limited to this subject.

In the usual presentation of roentgenographic technique no provision is made for differences in Roentgen-ray machines and equipment nor for variations in their operating characteristics. The technical procedures usually are based on a hypothetical man said to be of average size weighing 150 pounds, without providing for variations in 150-pound men nor for individuals of other sizes. By introducing a series of experiments for determining the operating peculiarities of each Roentgen-ray machine, by providing a simple experimental method of measuring the Roentgen-ray output of each equipment, and by basing exposures on the thickness and roentgenographic density of parts of the body, a method of perfecting a roentgenographic technique has been devised that may be used in any Roentgen-ray laboratory, irrespective of the apparatus it may contain.

The author particularly has kept in mind the needs of medical students in classes in roentgenology, those of Roentgen-ray technicians, and those of physicians either undertaking Roentgen-ray work for the first time or doing some roentgenographic work for themselves and their colleagues.

The author wishes to acknowledge the liberal use of the books and articles referred to in the bibliographies at the ends of the chapters, often without specific reference in the text. Of those who have assisted in the completion of this work, he is particularly grateful to Mr. L. C. Niedner and Mr. W. S. Werner for helpful suggestions, to Mr. John M. Haislip for correcting the manuscript, to Mrs. Z. O. Jennings for performing much of the experimental work, to Miss Thelma Morris for the preparation of the drawings, to his secretary, Miss Norma Worthington, for her industry and care in seeing the manuscript through its numerous changes, and to the publishers, Messrs. Lea & Febiger, for their many courtesies. D. A. R.

LITTLE ROCK, ARKANSAS.

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ROENTGENOGRAPHIC TECHNIQUE.

CHAPTER I.

ELECTRICITY AND ELECTRIC CURRENTS.[1]

ALL matter, whether gaseous, liquid, or solid, can be divided into molecules that are composed of much smaller subdivisions known as atoms. Until recently it was thought that atoms could not be further split up, that they were the smallest subdivisions of each known substance, and that differences in chemical elements were produced by differences in atomic and molecular arrangement. More recent studies, however, have shown that atoms have an internal structure probably consisting of a central mass or nucleus which has a positive electrical charge, surrounded by one or more negatively charged particles called electrons.

The chemical and physical properties of the different elements are believed to depend on the number and arrangement of the nuclear particle and electrons. The more complex the substance, the larger the nucleus and the greater the number of electrons. The hydrogen atom, with a simple nucleus and a single electron, is the least complex of all. The mass of its positively charged nucleus is 1800 times greater than that of its negatively charged electron. The number of electrons in atoms of the elements varies from 1 for hydrogen to 92 for uranium, the most complex of all. The number of electrons in an atom of a certain element is thought to be equal to the number of that substance in the periodic table; that is, it is equal to the number of the element when all are arranged in the order of increasing atomic weights.

All electrons are believed to be exactly alike. Within the atoms they are thought to be in continuous motion around the nucleus, a

[1] Not more than the simplest outline of the physics of electricity, Roentgen-ray machines and Roentgen-rays can be included. For a more complete discussion the reader is referred to the books by Robertson and Leggett.

motion similar to that of the planets around the sun. The negative electrical charge of each is the same. They are capable of existence and motion separated from the rest of the parent atom. Under the influence of electrical pressure they may be propelled at great speed.

For the student of electricity considerable importance is attached to the negative electrical charges of electrons and the positive charges of the nuclei. A body containing electrons in excess of its normal structure is said to be negatively charged; one containing less than the normal number of electrons is said to be positively charged. Bodies so charged attract one another. If they be connected by a conductor, electrons will flow until an electronic equilibrium is established. If, by mechanical or chemical means, as in a generator or battery, atoms can be dissociated so that a continuous supply of electrons is produced and sent through a suitable conductor, a current of electricity is the result.

Electrons do not pass through all bodies with the same ease. A substance that permits them to pass without serious obstruction is a good conductor. One through which they pass with difficulty, or not at all, is a poor conductor or an insulator. Copper and aluminum are good conductors. Glass, hard rubber, and mica are good insulators.

When positive and negative atomic portions are separated, there is an attraction between them and force is exerted which has a tendency to cause the electrons to reunite with the remainders of the atoms. This force, or pressure, by or upon the electrons, is spoken of as difference of potential, and is measured in arbitrary electrical units of electromotive force called volts. The quantity of electrons that flow through a conductor is measured in other units known as amperes, and the resistance of the conductor to the passage of the electrons in units known as ohms.

These units can be defined in terms of each other. Thus a volt is the amount of electromotive force or pressure that will cause an ampere of current to flow against a resistance of 1 ohm. An ampere is the amount of current that will flow against a resistance of 1 ohm with a pressure of 1 volt. An ohm is the amount of resistance which will require a pressure of 1 volt to cause a current flow of 1 ampere. The unit of quantity of electricity is the coulomb, which is 1 ampere maintained for one second. The unit of work is the watt, which is the amount of work that can be done with a current of 1 ampere and a pressure of 1 volt.

These units are too small or too large for measuring certain forms

of electricity, so that others a thousand times greater or smaller are used. Thus a kilovolt is 1000 volts, a kilowatt is 1000 watts, and a milliampere is $\frac{1}{1000}$ of 1 ampere. The kilovolt and milliampere are units constantly used in Roentgen-ray work.

Because the abstract conception of units of electricity is frequently difficult for a student to grasp, an illustrative comparison is often made between electricity in a wire and water in a pipe. The pressure of the water is comparable to voltage, the amount of water flowing to amperage, and the size of the pipe or the opening in it, with the friction between the water and pipe, to the resistance or ohms. Thus a certain pressure is required to cause water (electricity) to flow through a pipe (wire). The quantity of water (amperes) from the pipe (wire) depends on the size of the opening (resistance measured in ohms) and the pressure (volts). If the opening is large (resistance low), the flow of water (amperes of current) will be large and the pressure (voltage) will be maintained with difficulty. Obviously if there is no opening in the pipe (very high resistance), pressure (voltage) may be very high yet no water (current) will flow.

DIRECT AND ALTERNATING CURRENT.

There are two kinds of electric currents, direct and alternating. In a direct current the electrons all flow in one direction. This direction is from the negative side of the battery or dynamo, through the wiring and appliances, back to the generator.

In an alternating current there are very rapid but periodic changes in the direction of the flow of the electrons through a conductor, first in one direction and then in the opposite direction. Fig. 1 is a drawing of a curve used by physicists and engineers to illustrate an alternating current. In this figure the current represented by the part above the line is flowing in one direction, that below the line in the other. The arrows beneath show the direction of the current flow for each part of the curve.

In an alternating current the voltage is not constant as it is in a direct current. At A, Fig. 1, the voltage is zero. It increases to its maximum at B and then falls to zero again at C. At this point the direction of the current in the conductor changes; the voltage rises to its maximum at D and falls to zero at E. That part of an alternating current represented between points A and E is one cycle. A cycle, therefore, consists of a flow in one direction and

then in the opposite direction back to the starting point. The curve in Fig. 1 represents three and a half cycles.

Although currents of a greater or less number of cycles per second are generated, the common form of alternating current is one of 60 cycles. In a 60-cycle alternating current there will be 3600 cycles per minute. Inasmuch as each cycle consists of a flow of current in two directions, in one second there will be 120 changes in direction, or 7200 in one minute.

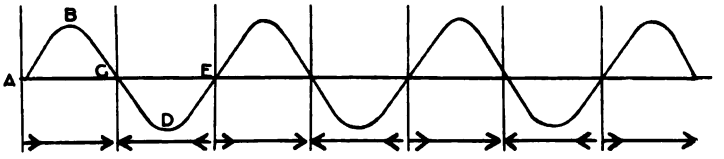

FIG. 1.—Curve used by physicists to illustrate alternating current. The arrows indicate the direction of electron flow.

Alternating current is in more common use than direct current for lighting and industrial purposes. Direct current must be transmitted to the consumer at the voltage at which it leaves the generator. Because of this, a direct current of a considerable number of amperes must be transmitted over a large conductor and disposed of in the vicinity of the generating plant. By passing an alternating current through devices known as transformers the voltage and amperage can be changed. By so doing, an alternating current may be altered so that the voltage is very high and the amperage is low, the power or wattage remaining the same. In this form it may be sent for long distances over a relatively small conductor.

Alternating current is usually generated at from 2300 to 6600 volts. At this voltage it may be distributed throughout a community lying within a radius of 3 to 6 miles of the generating plant. This voltage is too high to send over wires into dwellings and business buildings. In the vicinity of buildings where it is to be used the current is passed through small transformers in which the voltage is reduced to 220 or 110 and the amperage is raised. These transformers are usually placed on poles in the street or alley close to the buildings that are supplied from them or in special transformer rooms in the buildings themselves.

By passing an alternating current through large transformers adjacent to a generating plant almost any voltage can be obtained.

The resulting electricity may be sent over transmission lines for long distances. At the termination of the lines the voltage is reduced by other transformers to 2300 volts for distribution in a community, being again reduced by means of other transformers before it is used. Because alternating current can be distributed over large areas in this manner, large hydroelectric and other generating systems are being constructed.

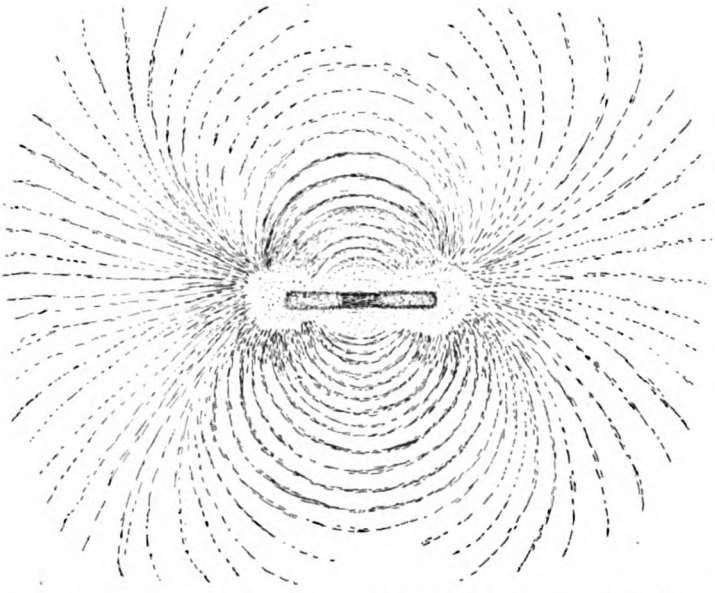

FIG. 2.—Pattern formed by iron filings on a paper held over the ends of a horseshoe magnet, demonstrating the presence of lines of force in the magnetic field of the magnet.

ELECTROMAGNETIC INDUCTION.

If iron filings be scattered over a piece of paper resting on the ends of a horseshoe magnet and the paper gently tapped, the filings will arrange themselves in a pattern like that illustrated in Fig. 2. If a wire carrying an electric current be passed through the center of the paper, the filings will arrange themselves in concentric circles around the wire. These patterns demonstrate the presence of a magnetic field around the ends of a magnet and surrounding a wire carrying an electric current, the lines formed by the iron filings illustrating the occurrence within the magnetic field of lines of force. A coil of insulated wire carrying an electric current is surrounded by

a magnetic field and is called a solenoid. If a bar of iron be passed through the center of the coil, the iron will become magnetized and an electromagnet be made.

If a wire forming a closed circuit be moved through or within a magnetic field in such a way that the wire passes through lines of force, a current will be produced within the wire. Or if the circuit be stationary and the magnetic field be changed by starting and stopping the electric current, a similar indirect current will be created in the closed circuit. Electric currents produced in this way depend on electromagnetic induction for their origin, and are called induced currents.

An induction coil is an instrument used in producing an induced current. It consists of an iron core around which are wrapped a relatively few turns of rather coarse wire, the ends of which are brought out of the coil and connected with a source of direct electricity. This coil of wire is known as the primary coil, and the circuit formed by it, the primary circuit. Around the primary coil, but insulated from it, there is a secondary coil, consisting of a large number of turns of finer wire, which makes a secondary circuit. When the primary circuit is closed or opened, a momentary current is induced in the secondary circuit by the changing of the relationship between the lines of force in the magnetic field and the turns of wire in the secondary coil. If the primary circuit be rapidly opened and closed by an instrument called an interrupter, a current will be induced in the secondary circuit which is a high-voltage alternating current.

A transformer is constructed somewhat like an induction coil. One form has a circular or rectangular core made of iron (Fig. 3), on one side of which is placed the primary coil, and on the other the secondary coil. The two coils are carefully insulated from each other, usually by placing them in a tank or container filled with oil of high insulating quality. In the most efficient form the primary surrounds the core and the secondary is built around the primary coil.

A transformer is actuated by alternating current. The changes in the relationship of the lines of force in the magnetic field of the primary coil and the wires of the secondary coil, necessary for an induced current, are produced by the alternations or rapid changes in direction in the current through the primary circuit.

The voltage and amperage in the secondary circuit of a transformer depend on that of the primary circuit, and on the relation-

ship between the number of turns of wire in the primary compared to the number in the secondary coil. The ratio of the number of turns in the primary winding to the number of turns in the secondary winding is spoken of as the ratio of the transformer. For example, if there be 100 turns of wire in the secondary for each turn in the primary, a transformer is said to have a 1 to 100 ratio. Such a transformer will create an induced current in the secondary circuit which has a voltage approximately one hundred times greater and an amperage approximately one hundred times less than that of the primary circuit, and because it increases or steps up the voltage, it is spoken of as a step-up transformer. In Fig. 3 is illustrated a 1 to 10 step-up transformer, the primary coil having 2 turns and the secondary 20 turns of wire. To illustrate its action, it may be

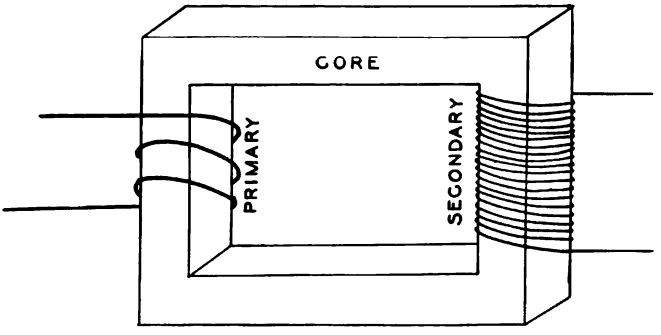

FIG. 3.—Diagram illustrating the construction and action of a transformer.

assumed that with such a transformer, for each volt of the primary current the secondary current will have 10 volts, and for each primary ampere there will be 0.1 ampere in the secondary current. If a current of 110 volts and 20 amperes be sent through the primary of such a transformer, the secondary current will be one of 10×110 or 1100 volts and $20 \div 10$ or 2 amperes. Because of some resistance in the windings and some loss in the iron core, neither the voltage nor the amperage of the induced current will have quite the values given in this illustration.

Not all transformers are step-up transformers. If the ratio of the number of turns in the primary and secondary coils be reversed so that the secondary has fewer turns than the primary, because the voltage will be stepped down or reduced, the transformer is called a step-down transformer. A step-down transformer will decrease

voltage and increase amperage according to its ratio. In Fig. 3, if the two coils be reversed, the transformer will become a 10 to 1 ratio step-down transformer. In such a transformer, for each volt of primary current, approximately 0.1 volt of secondary current, and for each ampere of primary current, approximately 10 amperes of secondary current will result.

ELECTRIC CURRENTS OF A ROENTGEN-RAY MACHINE.

A Roentgen-ray machine uses three forms or kinds of electricity. One of these is the low-voltage high-amperage current received from the generating plant for use in the machine. This is usually alternating current of either 110 or 220 volts, the number of amperes varying from 10 to as many as 100 or more. When only direct current is available, a modern Roentgen-ray machine requires that this be changed to alternating by means of a rotary converter, the voltage of the current thus produced being usually 170 volts. The second kind of electricity has a very high voltage and a low amperage. The voltage of this varies from 30,000 to 300,000, or from 30 to 300 kilovolts. Its amperage varies from 1 to 100 milliamperes or from 0.001 to 0.1 ampere. In rare instances, as many as 500 milliamperes may be produced for very brief periods of time. The third kind of electricity has a maximum of 15 volts, with an amperage that varies from 3 to 5½ amperes. This current has the special purpose of heating the filament of the Coolidge tube when such is used.

In a Roentgen-ray machine the current in the supply line and primary circuit, in the motor circuit, and in the filament circuit as far as the filament transformer, requires a rather heavy wire. The supply line should be heavier than the others, especially if it is quite a distance from the transformer to the switch. Because a current of this sort is unpleasant to touch, the wires should be insulated. Loose connections may cause troublesome fluctuations in the high-voltage circuit.

The high-voltage current may be carried over a small wire. This current will jump an air gap, so the connections need not be tight. The usual insulation on electric wires is not sufficient to insulate against this voltage. Rigid tubes of mica or bakelite are required. Except around rectifiers and vertical or horizontal fluoroscopes, usually no attempt at insulation is made. For this reason, the high-

voltage current should be carried by an overhead system high enough to be removed from accidental contact with operator or patient.

With a suitable overhead system, accidental contact with the high-voltage current is most apt to occur around the Roentgen-ray tube. Such contact is extremely unpleasant and dangerous. At the least it will knock a person down and may cause bad superficial burns. Several instances have been reported where such contact has resulted in the death of the patient or operator.

The low-voltage current of the filament circuit may be carried over a small wire. The connections in this circuit must be very tight and firm—soldered connections are best—or there will be fluctuations in the current from loose connections. Bare wires carrying only the filament current may be handled, as the current is not strong enough to produce even unpleasant sensations.

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CHAPTER II.

ROENTGEN-RAY MACHINES.

ROENTGEN-RAYS are produced by the passage of a high-voltage low-amperage electric current through a Roentgen-ray tube. A Roentgen-ray machine and its accessories comprise all of the apparatus and instruments necessary or useful in the production and control of such a form of electric current, its delivery to a Roentgen-ray tube, and the use of the rays in fluoroscopy, roentgenography, or treatment.

In the earlier days this current was produced by a static machine or an induction coil, and was used in gas tubes. In this country at least, the induction coil has been so nearly replaced by the interrupterless type of machine that older forms are of little more than historic interest. In all but a few laboratories, the Coolidge tube has also replaced the gas tube. For these reasons, neither the induction coil nor the gas tube will be described.

Because of the large number of different models of Roentgen-ray machines in use and being built by American manufacturers, a detailed description of one particular model is impracticable. Although differing considerably in size, in outward appearance, in the number and kind of accessories, and in other particulars, all of them are alike in their essential parts. Since this is true, the description of a Roentgen-ray machine may be in general terms applicable to any of the interrupterless type. For a detailed description of a particular model, the manufacturers should be consulted.

For purposes of description, the parts of the interrupterless type of Roentgen-ray machine may be grouped under five headings. One of these is the supply line and the current it carries; the others are the four chief electrical circuits of the machine itself. These are as follows: (1) the primary circuit; (2) the motor circuit; (3) the secondary circuit, and (4) the filament circuit. All of the different parts of the machine are designed to function with one or more of these four circuits.

SUPPLY-LINE CURRENT.

For the operation of a Roentgen-ray machine, the best form of electric current is alternating of 60 cycles and 220 volts for larger

machines, and 110 volts for some of the smaller ones. Where other forms of alternating current must be used, especially constructed machines are necessary. Direct current must be changed to alternating by means of a rotary converter. This adds both to the size and cost of the equipment. In inquiries concerning a Roentgen-ray machine, the kind of current and the voltage to be used should be specified.

Electric current for a Roentgen-ray machine should be as free as possible from fluctuations. Alternating current is distributed throughout a city or community at high potentials—usually at or above 2300 volts. By passing through step-down transformers, this is reduced to 220 or 110 volts in or near the buildings in which it is used. Different buildings containing various kinds of electrical apparatus may be connected to one of these transformers. If this be true, the demands on the transformer will vary from time to time, causing variations in the voltage supplied from it. Whenever possible, to eliminate this source of variable voltage, a Roentgen-ray machine should have a step-down transformer to which it only is connected.

The supply-line current is brought into the Roentgen-ray room at either 110 or 220 volts over a 2- or 3-wire main line. If over a 2-wire main, the voltage may be either 110 or 220; if over a 3-wire main and the electric service is single phase, it is usually 110 and 220 volts. In a 3-wire main the middle wire is called the neutral wire. From it to either of the outside wires will be 110 volts, while between the two outside wires there will be 220 volts. A 3-wire main, therefore, provides current of both 110 and 220 volts. These wires should end in a 2- or 3-pole, properly fused, safety switch. This is called the supply-line switch (SLS, Figs. 6 and 7).

THE PRIMARY OR LOW-VOLTAGE CIRCUIT.

The primary or low-voltage circuit is so named because the primary coil of the Roentgen-ray step-up transformer is included in it, and because it carries low-voltage electricity in contradistinction to the secondary or high-voltage circuit. It begins at the supply-line switch and includes the primary coil of the transformer. In this circuit are the devices for varying the primary current; a switch for closing the circuit, called the Roentgen-ray switch; usually a voltmeter for indicating or measuring the voltage passing through it; and sometimes an overload relay circuit breaker.

A transformer can perform but one function. It can change, according to its ratio, the voltage and amperage of the alternating current which it receives. For commercial lighting and power purposes the voltage impressed on it is constant, so that the voltage coming from it is also constant. If, as in a Roentgen-ray machine, it is necessary to vary the voltage from the transformer, the variation must take place in the primary circuit by changing the voltage going into the transformer. In other words, differences in output depend on differences in input. These variations are controlled by the operator with instruments for changing the primary voltage. Such instruments are of two kinds: autotransformers and rheostats.

A rheostat is made up of coils or sheets of metal having a high resistance, which hinder or retard the flow of electric current passed through them. By means of a movable handle or control the amount of resistance can be changed, thus altering the amount of

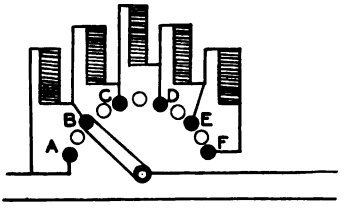

FIG. 4.—Diagram illustrating the construction and action of a rheostat.

current permitted to pass through the primary circuit. Fig. 4 is a diagram of such an instrument having five coils of resistance wire. If each coil will reduce the voltage 20 volts at a given amperage from a current of 220 volts, the primary current may be varied from 220 to 120 volts by moving the control handle. For example, if the handle is on button A, none of the resistance coils will be in the circuit and the full 220 volts will pass. If the control handle is on button C, two of the coils will be in the circuit; each will cause a 20-volt reduction, so that 180 volts will pass the rheostat. If the control handle is on button F, all of the rheostat will be in the circuit, the voltage will be reduced 100 volts, and 120 volts will pass.

An autotransformer performs the same function as a rheostat but depends on an induced current for the variation in the primary current. An autotransformer consists of a core made up of sheets of soft iron around which is wound a number of turns of a large, insulated copper wire. When a current is passed through this wire,

there will be a self-induced current in each turn, the voltage of which will be that fraction of the impressed voltage that each turn is of the total number of turns of wire. Such an instrument is diagrammatically illustrated in Fig. 5. In this figure the autotransformer has 10 turns of wire, so that if the primary current is 200 volts, the self-induced current in each turn will be 20 volts. By moving the control handle, the primary current may be altered, in steps of 20, from 20 to 200 volts.

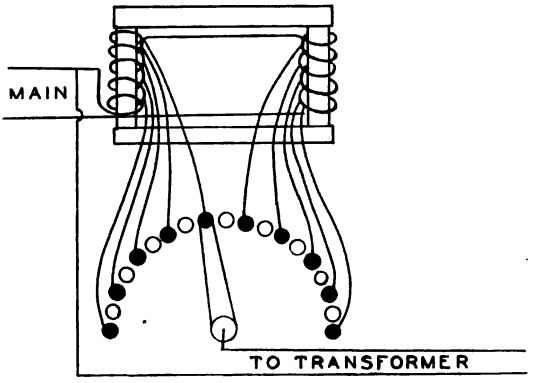

FIG. 5.—Diagram illustrating the construction and action of an autotransformer.

Autotransformers are much more complex than the diagram in Fig. 5 would indicate, the drawing being intended only to illustrate their method of construction and action. Each has a larger number of turns of wire, either around one or both sides of a rectangular closed core, from which, at suitable intervals, taps are taken off which deliver the desired voltages to the controls on the switchboard. The autotransformer may not only serve as an apparatus for control of the voltage in the primary circuit, but from it also may be obtained suitable voltages for the supply of other parts of the machine. Electricity for the motor circuit, the filament circuit, the magnetic Roentgen-ray switch, even a small electric globe to illuminate the control panel, etc., may be obtained from the autotransformer.

Machines that were made primarily for gas tubes have rheostat controls (Fig. 6). Other models, made for Coolidge tubes, depend primarily for voltage variations on autotransformers. Practically all small and medium-sized Roentgen-ray machines of recent manufacture are equipped only with autotransformer control. Some

machines, particularly the larger ones, have both autotransformers and rheostats in the primary circuit (Fig. 7).

For use with a Coolidge tube, an autotransformer is much better than a rheostat. In a rheostat-controlled transformer, changes in

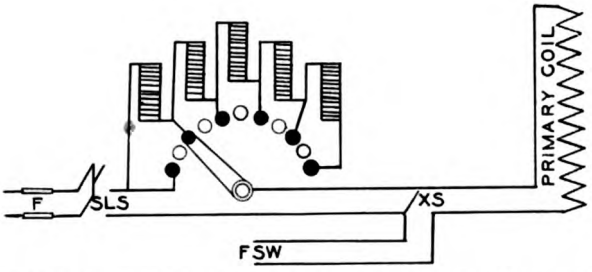

FIG. 6.—Primary circuit of a Roentgen-ray machine with rheostat control and simple switches. F, fuses; SLS, supply line switch; XS, Roentgen-ray switch; FSW, foot switch.

amperage in the secondary circuit will cause rather marked changes in secondary voltage, an increase in amperage causing the voltage to drop and a decrease in amperage causing the voltage to rise. In some machines with rheostat control, or when a combined control is used, these changes are often so sudden and so marked that it is

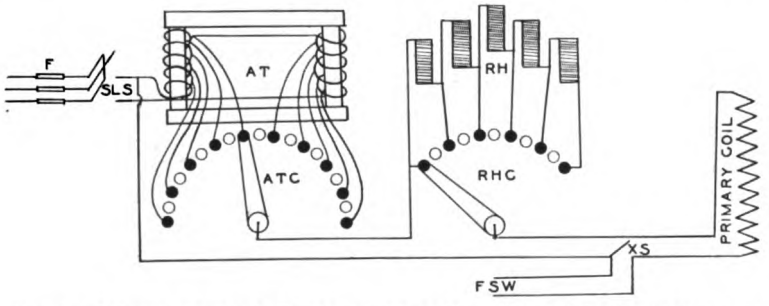

FIG. 7.—Primary circuit of a Roentgen-ray machine with combined autotransformer and rheostat control. F, fuses; SLS, supply line switch; AT, autotransformer; ATC, autotransformer control; RH, rheostat; RHC, rheostat control; XS, Roentgen-ray switch; FSW, foot switch.

difficult to control the secondary voltage. Similar changes take place with autotransformer control, but the effect of a change in amperage through the secondary circuit on the voltage is not nearly so marked as it is with rheostat control. Even with autotrans-

former control, a decided drop in secondary voltage will occur if a heavy secondary amperage is used.

The number of buttons on the rheostat or on the autotransformer, which determines the number of voltage steps available for use in the primary circuit of the transformer, and hence the number of available voltages in the secondary or Roentgen-ray circuit, varies with different models of machines. On one well-known model the autotransformer has 30 buttons. On the first button the primary current is 60 volts; it increases 5 volts with each succeeding button. There is also a rheostat with 23 buttons. On another make of machine the autotransformer has two controls. One of these begins with a primary current of 80 volts and increases 20 volts at each step until 180 is reached. The last button, used only in treatment, increases 40 volts and automatically throws a rheostat into the circuit. On this machine the second control increases the primary voltage in steps of 5 volts, intermediate between the steps on the first control. This machine has a 6-button rheostat. Other models of machines have differently graduated autotransformers and rheostats, the details of which should be learned from the makers.

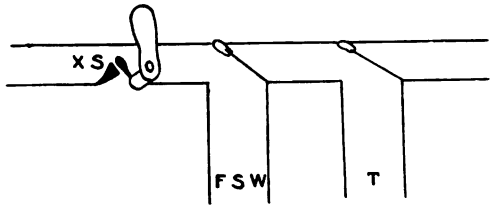

FIG. 8.—Simple Roentgen-ray switches in the primary circuit of a Roentgen-ray machine. XS, Roentgen-ray switch; FSW, a foot switch may be connected across this switch; T, an automatic timer may be connected across this switch.

All Roentgen-ray machines have a switch in the primary circuit, called the Roentgen-ray switch, which closes the circuit and admits the primary current into the transformer. The simplest form is a hand switch in one side of the primary circuit (XS, Fig. 8). When this is closed, the primary current flows from the control devices to the primary coil of the transformer, resulting in a high-voltage induced current in the secondary circuit. A foot switch or automatic timer, bridging across the Roentgen-ray switch, or at a different place in the primary circuit, the wires carrying the primary current, may be added (Fig. 8).

A much better Roentgen-ray switch is some form of magnetic switch controlled by a separate electric circuit. By closing the circuit through the magnet, the Roentgen-ray switch is closed, admitting the primary current to the step-up transformer. With a switch of this sort the wiring of the primary circuit is always of the same length, the contacts are large so that arcing at the opening and closing of the switch is reduced to a minimum, the operator does not have a number of switches to open and close, and there may be a number of ways to control the circuit through the magnet. Among the latter may be mentioned a hand switch, a foot switch, an automatic timer, a push button for continuous operation

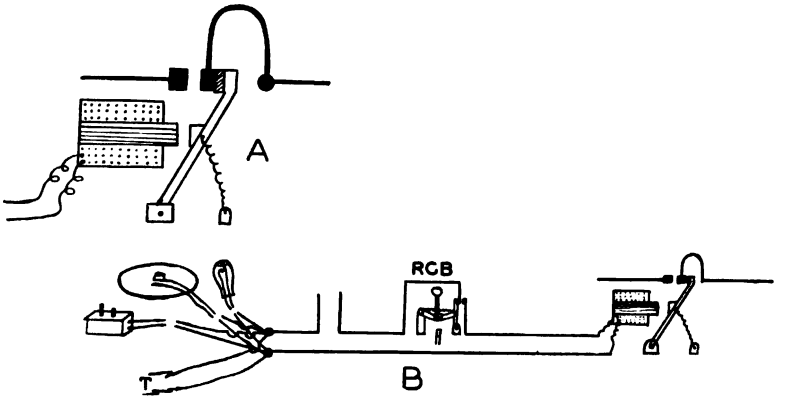

FIG. 9.—A, magnetic Roentgen-ray switch either in one or both sides of the primary circuit. B, circuit energizing a magnetic Roentgen-ray switch showing four ways in which the switch may be closed. The supply for the magnetic switch may come from the supply line or the autotransformer. T, automatic timer; RCB, relay circuit breaker.

as in treatment, and an attachment by means of which the circuit is opened and closed by the grid of a Potter-Bucky diaphragm (Fig. 9).

A voltmeter and an overload circuit breaker may be included in the primary circuit. The primary voltmeter should be connected across the primary wires between the control devices and the Roentgen-ray switch. It is called a prereading voltmeter because it registers the voltage of current passing the controls and which will be admitted to the transformer when the Roentgen-ray switch is closed. On some machines these are calibrated in alternating current volts. Others are called potential indicators and are calibrated in arbitrary scales reading from 1 to 100. Still others

are calibrated in secondary voltage either as average or peak kilovolts, indicating that the particular low-voltage primary current

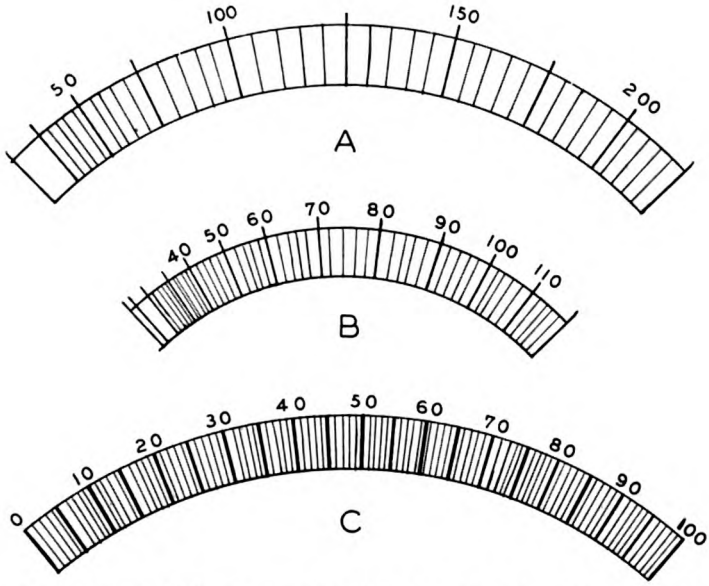

FIG. 10.—Scales of different types of voltmeters. A, scale reading in alternating current volts; B, scale reading in peak kilovolts; C, so-called potential indicator, the scale reading in arbitrary divisions.

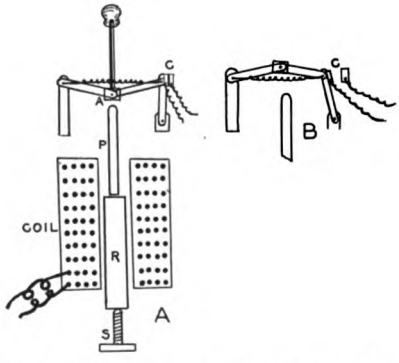

FIG. 11.—One form of overload relay circuit breaker. The coil is in the primary circuit. If an unusually heavy load is sent through the coil, the rod, R, is drawn into the coil, forcing the plunger, P, against A, pushing it past the center position, the spring opening the contact, C, breaking the circuit to the magnetic Roentgen-ray switch, and the switch opens. By means of the screw, S, the sensitiveness of the apparatus may be adjusted. A, contact closed; B, contact open.

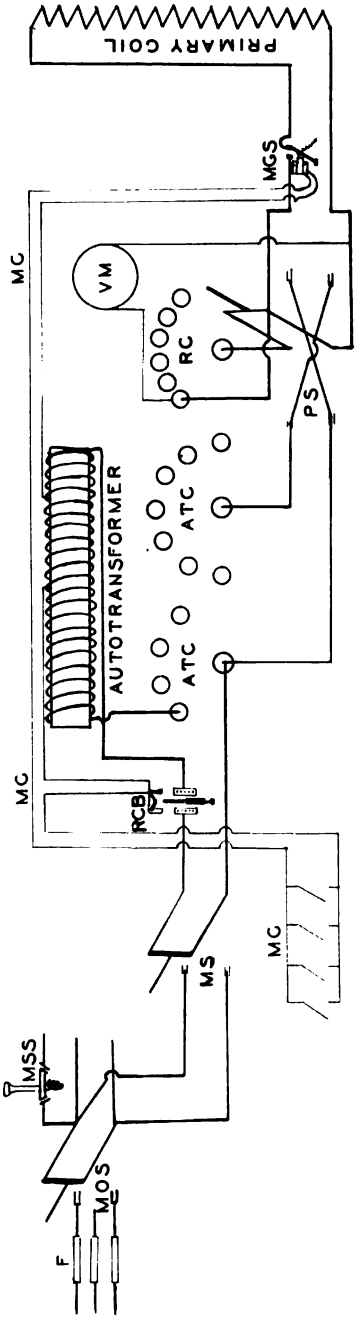

FIG. 12.—Wiring diagram of the primary circuit of a Roentgen-ray machine including a magnetic Roentgen-ray switch. MOS, motor switch; MSS, motor starting switch; MC, circuit of the magnetic switch; RCB, relay circuit breaker; ATC, autotransformer controls; RC, rheostat control; VM, voltmeter; PS, pole-changing switch; MGS, magnetic switch.

flowing through the instrument will produce approximately the indicated kilovolts in the Roentgen-ray or high-voltage circuit (A, B, and C, Fig. 10).

An overload circuit breaker is a safety device sometimes installed in the primary circuit (Fig. 11). If there is an unusually heavy load, the circuit breaker automatically opens. Such a load may come from a spark-over in the secondary circuit to the apparatus or patient, or from an unintentionally large primary current. In case of accidental spark-over or unusually heavy current, the opening of the circuit breaker stops it, thus preventing serious injury to any person or the apparatus.

STEP-UP OR ROENTGEN-RAY TRANSFORMER.

The low-voltage high-amperage current of the supply line and the primary circuit is converted into the high-voltage low-amperage current of the secondary or Roentgen-ray circuit in the large step-up or Roentgen-ray transformer. This transformer has a rectangular closed core, with the primary coil around one side and the secondary coil around the other, or the coils may be wound one over the other, the two windings being thoroughly insulated from each other. The core and the coils are immersed in oil of high insulating quality inclosed in a rectangular box of metal or special non-conducting material. The purpose of the oil is to insulate the coils from each other and from the container.

The ratio of the number of turns in the primary winding of the Roentgen-ray transformer to the number of turns in the secondary winding, spoken of as the ratio of the transformer, is usually such that the maximum secondary voltage is delivered when the primary is connected directly across the supply line without the voltage being reduced by a rheostat or an autotransformer. For example, one that has a capacity of approximately 100 kilovolts and is made to operate on 200 volts of primary current will have a ratio of about 1 to 500. This means that for each turn of wire in the primary there will be 500 turns in the secondary coil. In such a transformer, for each volt that is impressed on the primary, 500 volts will be induced in the secondary; and for each 0.002 ampere or 2 milliamperes passed through the secondary winding, one ampere will pass through the primary. If 200 volts be sent through the primary coil, 100,000 volts or 100 kilovolts will be induced in the secondary.

The two heavy wires of the primary circuit usually enter the

transformer through binding posts attached along one side of the case (P, Fig. 14). A resistance carbon connects these two wires to protect the primary coil from surges. The resistance of this carbon is sufficiently high to prevent any undue loss of primary current; but high-voltage currents will pass through it, thus protecting the primary coil from damage. The terminals of the secondary coil of the transformer emerge near the ends of the transformer case. The wires are surrounded by insulating tubes of mica, bakelite, or some similar material, to prevent the high-voltage current from jumping to adjacent parts of the apparatus.

The current entering the transformer is alternating of a certain number of cycles. The high-voltage current leaving the transformer is also alternating of the same number of cycles. Each terminal is alternately negative and positive, once negative and once positive for each cycle. This change is spoken of as the change in the polarity of the transformer.

THE MOTOR CIRCUIT AND THE RECTIFIER.

A high-voltage alternating current is unsuited for use in the universal type Coolidge tube. The negative terminal of the transformer must be connected to the cathode terminal of the tube and the positive terminal of the transformer must be connected to the anode terminal of the tube. The current may be interrupted or pulsating but it must be unidirectional. For this reason there must be some device that will change the alternating to a unidirectional current. This is known as the rectifying device or rectifier.

The rectifier consists of a motor with one or two disks or a set of cross-arms, or some modification of one of them, attached to its shaft (Fig. 14). As will be seen later, the motor must revolve the disk or cross-arms at a definite speed. With 60-cycle alternating current this rate must be one revolution for each 2 cycles, or 1800 revolutions per minute. For alternating current of a different number of cycles, there may be other designs operating at other speeds. Such a motor is said to revolve in synchronism with the generator supplying the electric current, and is called a synchronous motor.

Because synchronous motors have a very low starting torque, they are provided with a special starting winding to bring them up to synchronizing speed. In starting, the current is first sent through this winding until approximately the speed of 1800 revolutions per

minute is reached; it is then either manually or automatically disconnected, the current being sent through the running winding. The starting winding usually draws a rather heavy current and is not designed to remain in the circuit after the motor has attained the proper speed.

Because of this, such motors have a special starting switch or connection. This may be a double-throw switch which is closed one way for starting and then the other for running. There may be a switch which is closed to the left by hand and which, when released, is thrown to the right or running side by a spring. There may be a push-button and a knife switch, the button being closed until the running speed is reached and then released. There may be a centrifugal switch on the shaft of the motor which is thrown out of contact when the motor has reached a certain speed. If the motor

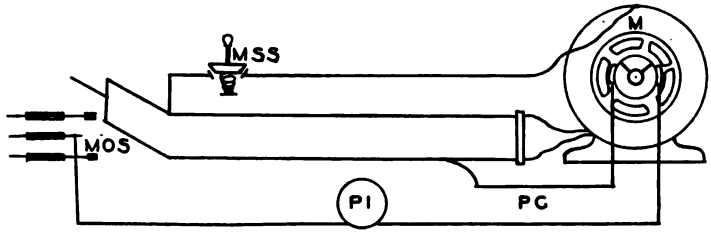

FIG. 13.—Motor circuit of a Roentgen-ray machine including the polarity circuit. The motor-starting switch, MSS, must be closed at the same time as the motor switch, MOS. PI, polarity indicator; PC, polarity circuit; M, motor.

is designed with a manually operated cut-out switch, after the motor has attained the proper speed, great care must be exercised in opening this switch. A failure to observe this precaution will, in all probabilities, cause the winding to burn out.

The presence of the synchronous motor as a part of a Roentgen-ray machine requires a separate electric circuit for its operation. The current supply is taken from the supply line or autotransformer and may be either of 110 or 220 volts. The motor switch is mounted on the control board. This circuit is diagrammatically represented in Fig. 13.

All types of rectifiers, whether of the cross-arm or disk type, are essentially similar in their operation, so the single disk type only will be described. The disk is made of mica, bakelite, or some other non-conducting material. On its edge, separated by 90 degrees, there are four metallic sectors. These are connected in pairs by

wires weaving back and forth through the edge of the disk or by a metal bar. As shown in Fig. 14, A is connected to B, and C to D. When the disk is turning, these sectors revolve on the inside of four collectors arranged in two pairs. Those of one of these pairs, separated by 180 degrees, are connected to the terminals of the secondary coil of the transformer (E and F), and those of the other pair to the tube circuit, X to the cathode side of the tube and Y to the anode side.

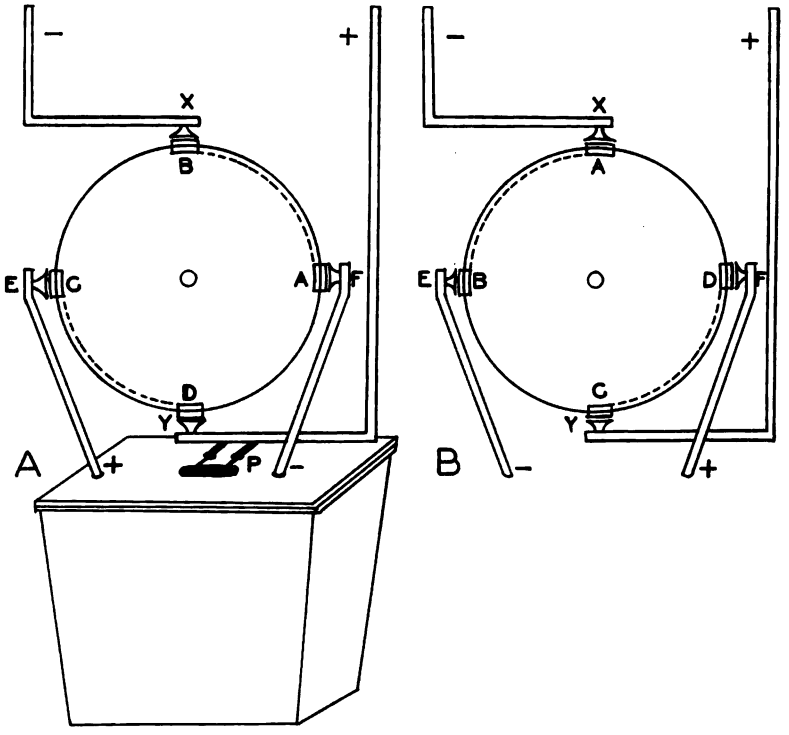

FIG. 14.—Illustrating the action of a disk type rectifier. The explanation is given in the text.

To understand the action of the disk rectifier, reference is made to Fig. 14, A and B. When the disk is in the position shown in A, the high-voltage current emerging from the negative side of the transformer will be at its maximum value or at the peak of the wave. It will flow through the collector to sector A, through the wire in the edge of the disk to B, from B to X, and then over the high-voltage

circuit to the cathode of the Roentgen-ray tube. After passing through the tube it will pass back over the other side of the circuit, through D and C into the transformer.

During the next half cycle of the alternating current, the polarity of the transformer will change, and the disk, revolving once for each two cycles, will make a fourth of a revolution and come to the position illustrated in B. In this position the current will pass from the negative terminal of the transformer through B and A to the cathode side of the tube, and back through C and D to the positive side of the transformer. By the time the polarity of the transformer has changed again, the disk will be in the position indicated in A, and the process will be repeated.

From this explanation it becomes clear that the speed of the disk must have a definite relationship to the alternations in the current. As stated before, with 60-cycle current, this is one revolution for each two cycles or 1800 revolutions a minute. If for any reason there should be a variation in the cycles of the current, the motor changes its speed to correspond, so that it always travels at a rate of one revolution for each two cycles. The disk of the rectifier must have a definite position on the shaft of the motor, which must be such that the sectors come opposite the collectors when the current is at the peak of the voltage.

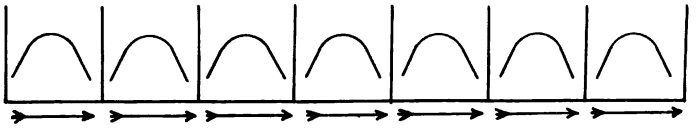

FIG. 15.—Rectified current, the arrows indicating the direction of electron flow. Compare with Fig. 1.

If Fig. 14 is now examined again, it will be seen that when the disk is in the position halfway between that represented in the two figures, the sectors will be halfway between the collectors, and no current will flow. This produces interruptions in the rectified current, making two pulsations for each cycle, one for each half cycle. It will be seen further that only the peaks of the high-voltage current will be rectified. While that portion of the current is passing which is of lower voltage, the sectors on the disk will be in the halfway position between the collectors, and no current will be flowing. This unidirectional, high-voltage, pulsating current is diagrammatically represented in Fig. 15, which should be compared with Fig. 1.

From a further consideration of Fig. 14, it may be seen that when the disk is in the position illustrated, the terminals of the transformer may be of the polarity indicated or just the opposite. In A, if the left terminal should be negative, the current would attempt to pass through C and D and through the tube from the anode side, which is impossible. If this occurs, the motor is said to be off polarity. To determine the polarity of the motor with reference to the transformer, an instrument known as a polarity indicator is provided.

The polarity indicator is a direct current voltmeter in a branch circuit in which there is a rectifying commutator on the motor shaft (Fig. 16). The commutator suppresses that part of the alternating current flowing either in one direction or the other, thus causing the needle of the indicator to move either to the right or to

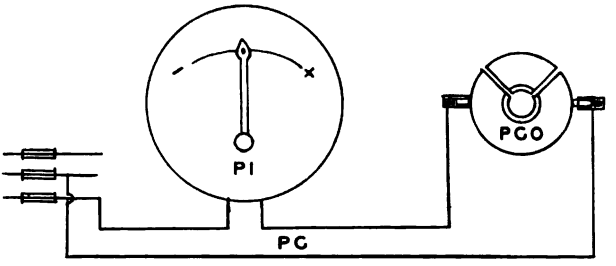

FIG. 16.—Polarity circuit. PI, polarity indicator; PCO, polarity commutator mounted on the end of the motor shaft.

the left. This enables the operator to determine whether the motor is in correct polarity with reference to that of the transformer. The supply for the polarity circuit may come from the supply line, the motor circuit, or from the autotransformer.

If the polarity is wrong, it may be changed by opening and closing the motor starting switch until the motor catches step in correct polarity, usually when the needle of the indicator swings to the right. Another method of obtaining the correct polarity is by means of a reversing or pole-changing switch (PS, Fig. 12). By means of such a switch, the polarity of the transformer is changed by changing the direction of the primary current into it. If a switch of this sort is in use, it is closed either to the right or left, depending on the deflection of the indicator needle.

A new type of rectification of the high-voltage electric current in the secondary circuit of a Roentgen-ray machine that has just been

introduced in this country is by means of large vacuum tubes known as kenetrons. One or more of these tubes in the secondary circuit serves the same purpose as the motor driven rectifier, thus being substituted for that part of the machine. The action of these tubes is much like that of the radiator type Coolidge tube when run directly from the terminals of the Roentgen-ray transformer (see page 52). On machines equipped with one or two kenetron tubes, one-half of the high-voltage alternating current waves—that part flowing in one direction—is suppressed by the tube, the other half being permitted to pass through the Roentgen-ray tube for the production of Roentgen-rays. On machines with four tubes, they are so connected in the high-voltage circuit that both halves of the high-voltage alternating current waves are rectified. At present machines with one or two tubes are used chiefly for radiographic work, those with four tubes for deep Roentgen-ray therapy.

The voltage of current rectified in this manner cannot be tested with a spark gap, making it necessary to depend on a chart supplied by the manufacturers for voltmeter readings giving different voltage values with different milliamperages (see Expt. 3, p. 100). It is quite probable that such machines have operating characteristics more like the unit type than like those with motor-driven rectifiers.

A kenetron has a hot cathode like a Coolidge tube, requiring a separate circuit, with a small transformer. In some machines the current through the tube is kept constant; in others, provision is made for altering it.

THE SECONDARY, HIGH-VOLTAGE, OR ROENTGEN-RAY CIRCUIT.

The secondary, high-voltage, or Roentgen-ray circuit begins at the secondary coil of the transformer, passes through the rectifier, and ends in the Roentgen-ray tube (Fig. 17). This circuit should be made of an overhead system of wires or tubes of substantial construction attached to the walls or ceiling of the room. From the overhead system the current is carried to the tube by wires wound on spring reels to keep them taut. The cost of an overhead system is so small that no Roentgen-ray machine should be operated without one. On a few machines the reels are attached to terminals on top of the cabinet and extend directly to the tube. Such wires are not much higher than an adult's head. With such

an arrangement the operator must be very careful to prevent contact with the wires while the current is on.

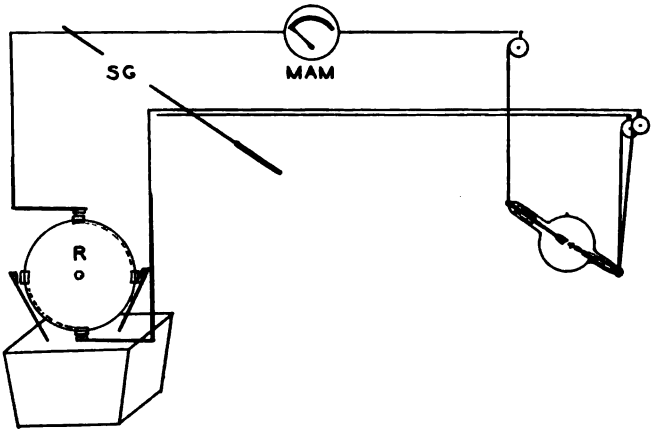

FIG. 17.—High-voltage circuit of a Roentgen-ray machine. The two wires to the cathode side of the tube also carry the filament supply. R, disk of the rectifier; SG, spark gap; MAM, milliamperemeter.

Across the high-voltage or Roentgen-ray circuit are placed the spark gap and the Roentgen-ray tube. Usually the milliamperemeter is placed in the high-voltage circuit. The latter is an instru-

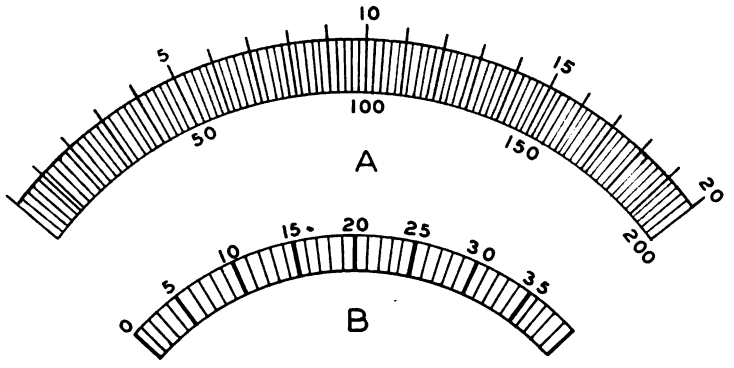

FIG. 18.—Scales of two types of milliamperemeters. A has a double scale, the bottom being ten times that of the top. The change from one to the other is made by a switch at the bottom of the instrument. B has a single scale.

ment for measuring the milliamperes of the high-voltage current going through the tube. In Fig. 18 are shown the scales of two

such instruments. A, in the figure, has a double scale, the top being ten times that of the bottom scale. The change from one to the other is made by a switch at the bottom of the instrument. If this switch be closed on the left side, the reading will be on the top scale; if closed on the right, it will be on the bottom scale. In B, there is a single scale reading from 0 to 40 milliamperes.

The spark gap in the high-voltage circuit is an instrument for measuring the approximate voltage of the current to the Roentgen-ray tube (Fig. 19). It is placed in parallel with the Roentgen-ray tube extending from one to the other of the high-voltage lines. The terminals of the gap may be in the form of needle points, moderately blunt points, a point and a plate, or spheres. The sphere gap is the most accurate and is used on all large therapy machines. On

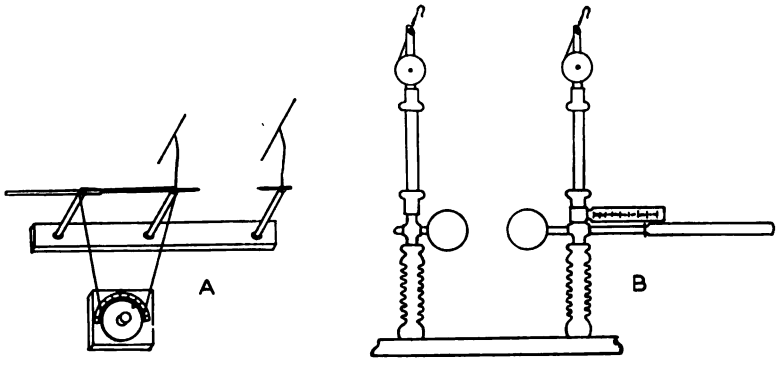

FIG. 19.—Types of spark gaps. A, a wall mounted point gap with the scale reading in inches. B, a portable sphere gap with the scale reading in peak kilovolts.

radiographic machines the spark gap may be one of moderately blunt points or of smaller spheres.

The spark gap is mounted on insulated supports. One side is stationary, the other movable. In measuring the sparking distance with a gap of this kind, the current is sent through the tube and the movable side is slowly pushed toward the stationary side until the spark flames across the gap. When this occurs, the current is shut off and the distance jumped by the spark is measured or read from a scale provided for that purpose. The blunt point gap is usually read in inches. The scale of a sphere gap is calibrated to read in peak kilovolts.

The voltage of the secondary circuit is described as being such that it will jump a gap of so many inches or centimeters, or is

spoken of as average or effective kilovolts (the root-mean-square kilovoltage of the engineers), or as peak kilovolts. Because a change is taking place in measuring kilovoltage from point to sphere gap, it is advisable in mentioning voltage in kilovolts to specify whether average or peak kilovolts is meant.

The blunt-point spark gap is not an absolutely accurate instrument. The discharge between the points is subject to variations due to the humidity of the air, the temperature, the altitude, and the degree of ionization of the air. It is sufficiently accurate, however, for practical roentgenographic purposes. The point gap is gradually being replaced by the more accurate sphere gap. Sphere gaps have become standard equipment on treatment machines but have not yet been universally adopted to measure voltage on roentgenographic equipment. The question of voltage measurements is discussed more fully in a later section.

ROENTGEN-RAY TUBES.

The earlier Roentgen-ray tubes were bulbs of glass from which the air had been partially exhausted and with electric terminals fused into projecting stems. There were many forms of these tubes. They all possessed one undesirable feature—the inconstancy of the vacuum within them. To overcome this difficulty the Coolidge tube, in which the vacuum is constant, was developed. Inasmuch as gas tubes are now used in only a few laboratories in the United States, a discussion of them is more or less of academic interest and will not be undertaken.

For general roentgenographic work, two forms of Coolidge tubes, the universal type and the radiator type, are available. The universal Coolidge tube (Fig. 20) consists of a spherical glass bulb about 7 inches in diameter, with two hollow glass arms or stems projecting from opposite sides. Fused into the end of the larger arm is an attachment which supports a molybdenum rod. To the end of the rod is welded a large piece of metallic tungsten known as the anode or target. In the smaller end of the tube there is a small flat coil of tungsten wire, the filament, which forms the cathode of the tube. The terminals of the filament are brought out through the glass and fastened to an electrical connection at the tip of the stem. The filament is surrounded by a small cylinder of molybdenum which acts as a focusing device.

Depending on the size of the focal spot, three forms of universal

Coolidge tubes are available. These are known as the fine, medium, and broad focus tubes. With a voltage of 98 peak kilovolts (6-inch spark gap), the maximum current that can be used with these tubes is 25, 40, and 80 milliamperes respectively. The manufacturers state that higher voltages with less milliamperage or greater milliamperages with lower voltages are permissible, provided the product of the voltage and milliamperage does not exceed that of those given. The fine focus tube is used chiefly for fluoroscopy and fine radiographic work, the medium focus tube for heavy radiography and superficial treatment, and the broad focus tube for moderately heavy treatments.

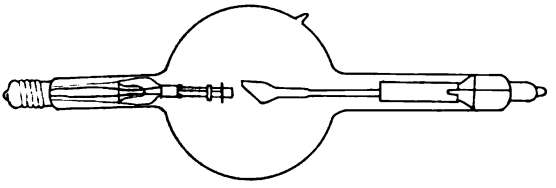

FIG. 20.—Universal type Coolidge tube.

The electrical energy applied to the universal type Coolidge tube should not exceed that given by the manufacturers. If it does, the tungsten of the anode will melt, be changed into a vapor, and collect as a black deposit on the inside of the bulb. A deposit of this kind makes the tube more likely to puncture. With a low milliamperage a universal tube can be run until the target becomes white hot without damage to the tube. If run in this way, the danger point is reached when the metal parts become so hot that the gases contained in them are driven out and act as a conductor to carry the heat to the glass of the bulb, thus making it more liable to puncture.

The radiator type Coolidge tube (Fig. 21) has a glass bulb about $3\frac{3}{4}$ inches in diameter. The focusing device around the filament is a hemispherical shell. The filament is essentially similar to that of the universal type. The anode or target is a small button of tungsten fused into the end of a solid copper rod. This rod is carried out through the glass of the stem and has attached to it a number of copper disks which make up the radiator. The heat from the target is conducted by the copper rod to the radiator which cools in the air. As will be explained later, the radiator tube may be run directly from the terminals of a transformer without rectification of the current. When operated on either rectified or non-rectified current, the tube voltage should never exceed 85 peak kilovolts or a 5-inch

spark gap. Two types are available for general radiographic work, one with a maximum permissible milliamperage of 30 and one with which the limit is 10 milliamperes. With either of these an exposure should not exceed twenty seconds.

More recently a third type of Coolidge tube has been developed and placed on the market. This is spoken of as the 5–100 radiator tube (Fig. 22), the 5 indicating a 5-inch spark gap or 85 peak kilovolts, and the 100 the number of milliamperes that may be used.

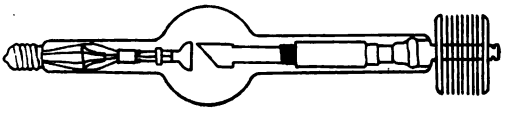

FIG. 21.—Radiator type Coolidge tube.

This tube has a bulb as large as the universal type. The filament and focusing device are like those in the smaller radiator type. The anode is a tungsten button set in a copper sphere, the sphere being channeled for the electrons to reach the target and for the emerging Roentgen-rays. The copper sphere is continuous with a copper rod that passes through the anode stem to a radiator similar to that on the smaller tube. Starting with the target cold, the maximum capacity of this tube is 100 milliamperes for ten seconds with a voltage equivalent to 85 peak kilovolts or a 5-inch spark gap.

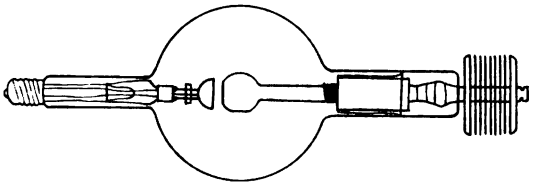

FIG. 22.—5–100 radiator type Coolidge tube.

These tubes have been in use for general radiographic work for a few years. Since they permit of the use of greater milliamperage than any of the other forms, making rapid roentgenography possible, they have been found admirably adapted for such work. The focal spot is smaller than that of the medium focus universal type and one can be used for roentgenographic work in place of either of the universal tubes. Although they cost more than twice as much as

other tubes, since they replace all three of the universal tubes for roentgenographic purposes, the purchase of one for a roentgenographic equipment is probably an economy.

THE FILAMENT CIRCUIT.

A Coolidge tube is as free from gases as it is possible to get it. During the final stages of the evacuation of the bulb, a high-voltage electric current is passed through the tube to heat the metal parts and drive out the gases contained in them. The vacuum is so high that a current of high voltage will not pass through the tube unless the filament is heated. Because of this a Coolidge tube cannot be used unless some provision is made for heating the cathode filament. This makes necessary the fourth electric circuit of a Roentgen-ray machine—the filament circuit (Fig. 23).

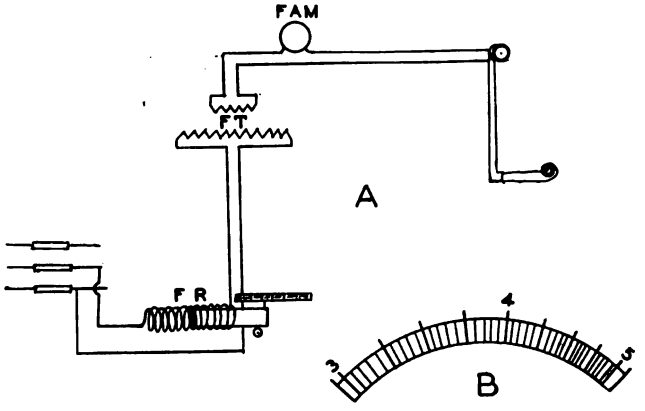

FIG. 23.—A, filament circuit of a Roentgen-ray machine. The filament transformer, amperemeter, and the conductors between the transformer and tube are in the high-voltage circuit also. FR, filament regulator; FT, filament transformer; FAM, filament amperemeter. B, scale of a filament amperemeter.

Electricity for the filament circuit is obtained from the current supply. It passes through a device known as the filament regulator (FR), which may be either an impedance resistance, a choke coil, or a rheostat, and then through a step-down transformer (FT). In this manner a current of 3 to 5 amperes and low voltage is delivered to the filament, the amperage of which is controlled by the filament regulator.

The filament regulator is mounted either in the control cabinet or on the wall adjacent to it. It has a variable control so that

the amperes through the filament may be altered through the entire range of fractions from 3 to 5 amperes. On many equipments there is included as a part of the instrument a filament scale, with arbitrary subdivisions, to make possible the repetition of a certain setting.

From the regulator the filament circuit passes to the primary of the filament transformer. This transformer reduces the voltage from 220 or 110 to the low voltage required. The secondary of the filament transformer is in the high-voltage circuit, so that the two coils of this transformer must not only be insulated from each other but also in such a way that the high-voltage current cannot pass into the primary coil. For the same reason it is either mounted on top of the cabinet, in the case with the Roentgen-ray transformer, or on the wall of the room.

From the filament transformer the current is carried by a complete circuit to the cathode end of the tube, and there, through an electrical connection, to the tube filament. The filament circuit may be made of two wires with the attached spring reels, or of a tube for one side of the circuit, a wire within it forming the other side. These wires or tubing also carry the cathode side of the high-voltage circuit so that they are a part of the overhead system.

Because of the low voltage in the filament circuit, it is essential that the conductors be of ample capacity to carry the filament current without undue voltage drop.

A very useful instrument that is sometimes installed in the filament circuit is an amperemeter which measures the amperes of current in the filament circuit (Fig. 23). It, too, is usually in the high-voltage circuit and is mounted on insulated brackets. This instrument has a scale reading from 3 to 5 amperes, subdivided by coarse markings into quarter amperes, and by fine markings into 0.05 amperes. The use of the filament amperemeter will be explained in a later section.

There is considerable fluctuation in the amperage of the current in the filament circuit of a Roentgen-ray machine, relatively small fluctuations in this circuit causing rather marked variations in the milliamperage through the Roentgen-ray tube (see Table IV). Such fluctuations often make it necessary to adjust the milliamperage through the tube by means of the filament regulator after an exposure has started. To overcome this irregularity and give a constant current and milliamperage through the filament and tube, instruments known as stabilizers have been developed. Some of these are designed to operate by stabilizing the current in the

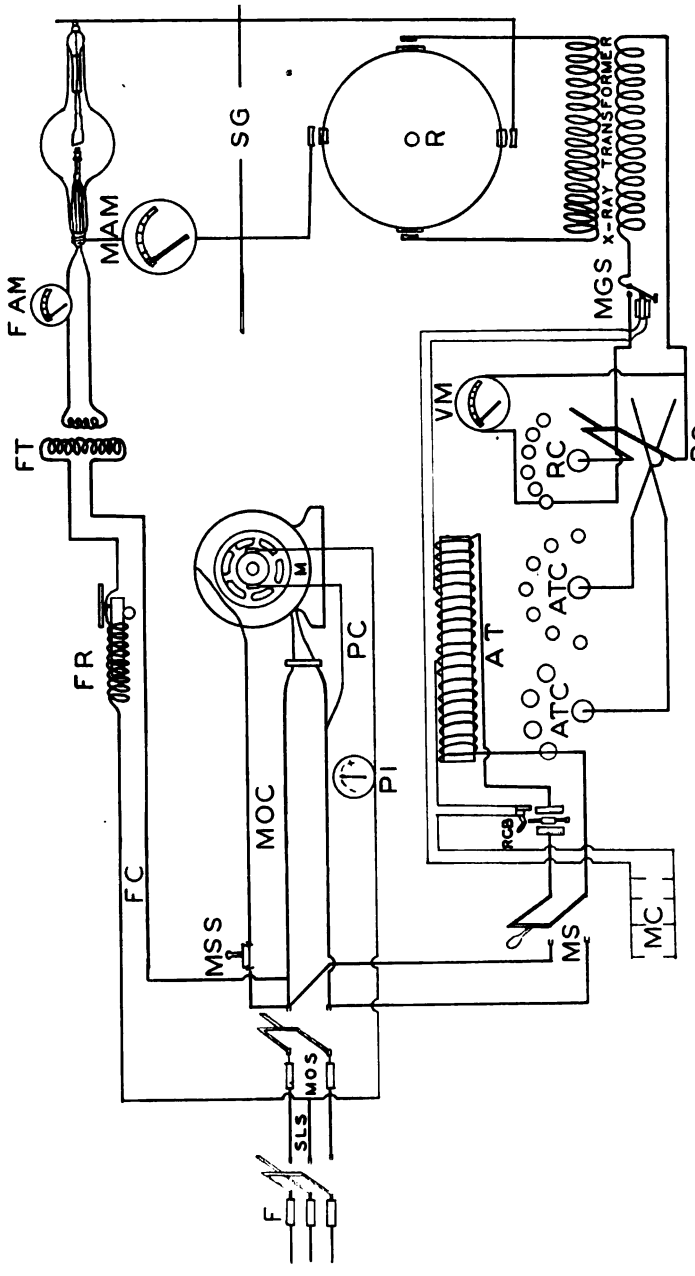

FIG. 24.—A complete wiring diagram of a Roentgen-ray machine of the interrupterless type with a motor-driven rectifier. This figure is included to show the connections of the different parts. The abbreviations are the same as those in preceding illustrations.

primary of the filament transformer. The Kearsley stabilizer is connected in the secondary circuits of both the filament and Roentgen-ray transformers. It not only stabilizes the milliamperage through the tube, but compensates for the differences in the resistance of the filaments of different Coolidge tubes so that one setting on the scale of the instrument will give the same milliamperage with different Roentgen-ray tubes. A stabilizer in good working condition and performing the function for which it is intended is a useful part of a Roentgen-ray machine.

Fig. 24 shows a complete wiring diagram of a Roentgen-ray machine of the interrupterless type with a motor driven rectifier, included especially to illustrate the connections of the different parts.

TWIN-TYPE APPARATUS.

In recent years a form of interrupterless Roentgen-ray machine has been developed which has two transformers and a double rectifying switch or rectifier. The transformers are immersed in oil in the same transformer case. Both rectifiers, usually of the disk type, are operated by the same synchronous motor. The operation of such a Roentgen-ray machine is so similar to that of the single transformer and single rectifier that additional description is unnecessary. The advantages of this particular apparatus are that the rectifiers may be considerably smaller, thus operating with less noise than the single rectifier, and the milliamperemeter may be connected between the two transformers and thus be at ground potential. It may be placed in the control stand where it can be more easily seen and read than in the high-voltage circuit. The operating characteristics of this type of Roentgen-ray machine are the same as those of the single transformer type.

WITH DIRECT CURRENT.

A transformer requires alternating current for its operation. In localities where the electric supply is direct current, this must be changed to alternating by a rotary or motor converter before it is sent into the Roentgen-ray transformer of a Roentgen-ray machine. The rectifier is usually mounted on the shaft of the converter so that the synchronous motor is eliminated. Since the polarity of the

rectifier and the transformer in such apparatus is always the same, the polarity circuit is also eliminated. With these exceptions, the operation of a machine using direct current is the same as that of one using alternating current.

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CHAPTER III.

ROENTGEN-RAY MACHINES (CONTINUED).

THE UNIT TYPE OF ROENTGEN-RAY MACHINE.

IN a Coolidge tube the electrons necessary to carry the high-voltage current from the cathode to the anode are given off by the heated tungsten of the cathode filament (see p. 66). As long as the anode of the tube remains at a temperature below the point where electron emission begins, the tube may be used directly attached to the terminals of a suitable transformer without rectification of the current. The radiator type Coolidge tube was especially designed to convey the heat from the tungsten button which forms the anode through the copper rod to the radiator which cools in the air. When operated directly from the terminals of a transformer and within the limits set by the manufacturer, the radiator type Coolidge tube will suppress that part of the high-voltage alternating current which attempts to pass from the anode to the cathode, while the electrons from the cathode filament will carry the other half-waves in the opposite direction for the production of Roentgen-rays. This ability of the radiator tube to rectify its own current makes possible a somewhat different and smaller form of Roentgen-ray machine known as the unit type (Fig. 25) which requires a brief description.

In unit type Roentgen-ray machines the motor circuit and the rectifier are not present. Most of the other parts of the interrupterless type described in the preceding chapter are represented. These include the supply line and its current, the primary circuit, the secondary circuit, and the filament circuit, with their various instruments and apparatus.

These machines may require either a 110- or 220-volt supply. Many of them are so constructed that, by a simple adjustment, either voltage may be used. If available, a 220-volt supply is preferable. If such a machine is to be installed in one room and not used as a mobile unit, a separate step-down transformer for its supply is desirable. The supply of a machine adapted to 110 volts may be obtained from the lighting circuit of the building in which the machine is used.

As in the larger machine, the primary circuit begins at the supply line and ends in the primary coil of the Roentgen-ray transformer. Several different varieties of control devices to change the primary voltage are used in the primary circuits of these machines. In some the control device is very simple and is limited to one that delivers a constant voltage through the circuit, this being such that a single voltage, that corresponding to a 5-inch spark gap or 85 peak kilovolts, is produced in the secondary circuit. In other machines a small autotransformer is used as a control device. Some of these are so constructed that three primary voltages are available, those producing a voltage in the secondary circuit corresponding to a 3, 4, and 5-inch spark gap. Others provide intermediate steps in the

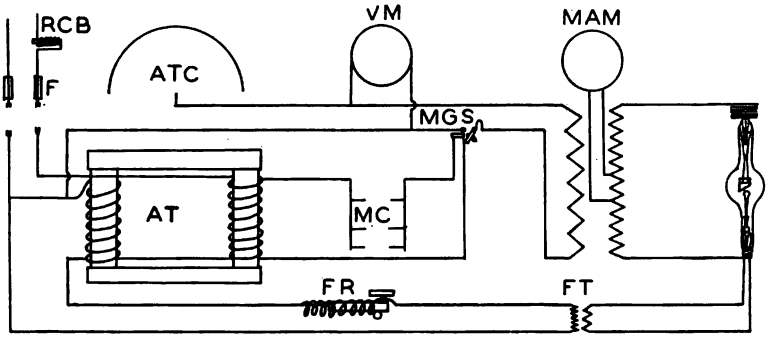

FIG. 25.—Wiring diagram of a unit type Roentgen-ray machine having a magnetic Roentgen-ray switch. The abbreviations are the same as those of the illustrations in Chapter II. Note the similarity between this and Fig. 24.

primary circuit, and hence in the secondary circuit, intermediate between the 3- and 5-inch spark gaps, as many as 20 such steps being obtainable. The details of the graduations in the autotransformer of a unit type machine must be learned from the manufacturers. The autotransformer in the unit type is more often used as a source for suitable voltages for other parts of the equipment than it is in the larger machines.

The primary circuit also usually contains a primary voltmeter and some form of Roentgen-ray switch. The voltmeter is usually connected between the autotransformer and the Roentgen-ray switch and serves as a very useful indicator of the primary and secondary voltages. As in the larger machines, a magnetic Roentgen-ray switch which may be operated by a hand switch, a foot switch, or a

timer, is the best form. A relay circuit breaker is an important safety device sometimes installed in the primary circuit.

Because of the limited capacity of the unit type of machine, the step-up or Roentgen-ray transformer is usually small and compact. The closed core, oil immersed type is most often used. The construction of the secondary circuit depends on the type of machine and kind of installation. The terminals of the secondary coil of the Roentgen-ray transformer are brought out of the case through rigid insulators. In the mobile unit the insulators often are continued to a height of 5 or 6 feet and are curved downward at the end. At their ends are attached the spring reels on which are wound the wires reaching to the tube terminals. On other types the insulators are short with the reels attached at their ends. In permanent installations the transformer may be mounted on the wall or under a fluoroscopic table with a modified and usually simple overhead system continuing the circuit to the tube in the tube stand or fluoroscope. In the latter forms the controls are in a separate unit either placed on a table or mounted on a pedestal convenient to the operator.

The milliamperemeter is connected to the neutral part of the high-voltage transformer in such a way that it will register the milliamperage, but, being at ground potential, there is no danger of high-voltage shock from it. It is usually mounted in the control panel. Because it is impossible to test with a spark gap the voltage of a current rectified by a radiator tube, this instrument is omitted.

The filament regulator is mounted in the control board. The filament transformer is often placed in the same container and insulated by the same oil as the step-up transformer. The filament circuit is completed by two electrical conductors leaving the transformer case through one of the insulators, these conductors being attached to the double reels connected to the cathode terminal of the tube. They also serve as the cathode side of the high-voltage circuit.

Mobile units for bedside work in hospitals, all of the portable Roentgen-ray machines, all of the special dental machines, many fluoroscopic units, and other simple installations are of the unit type. The essential parts of all of these varieties of machines are the same, and they have much the same operating characteristics. There are, however, considerable differences in their capacities and many differences in the details of their construction.

When used for the purposes for which they are intended and operated within their rated capacity, the unit types of Roentgen-ray

machines are excellent apparatus. With either the 10- or 30-milliampere radiator type tube, they may be operated up to 5 milliamperes and a voltage equivalent to a 4- or 5-inch spark gap (70 to 85 peak kilovolts) for fluoroscopy. Equipped with a 30-milliampere radiator type tube, they may be used for roentgenographic work up to 30 milliamperes at voltages between a 3- and 5-inch gap. Exposures should not exceed twenty seconds. Rapid roentgenography, especially important in the examination of the chest and gastrointestinal tract, cannot satisfactorily be done with the unit type of equipment, so this form is unsuited as a general purpose diagnostic machine.

THE OPERATION AND CARE OF A ROENTGEN-RAY MACHINE.

The multiplicity of types makes it impracticable to attempt to give detailed instructions for the operation of any one Roentgen-ray machine. In making a Roentgen-ray exposure, as a general rule the following steps are necessary:

The supply-line switch should first be closed. If there is any likelihood of an unskilled person either working around the machine, as in cleaning it, or meddling with it, this switch should always be open when the machine is not in use.

Next, start the motor, and if necessary, correct the polarity. If the control board includes a double-throw pole-changing switch, this should be left open to be closed as the last act before the exposure begins. If there is no polarity switch, it may be necessary to open and close the motor switch until polarity is correct, usually when the indicator needle swings to the right. The closing of the motor switch also may close the primary of the filament circuit and light the filament in the tube. If the filament switch is separate, it must be closed.

The next step is the adjustment of the current in the primary circuit and in the filament circuit so that the voltage and milliamperage of the current delivered to the Roentgen-ray tube will be appropriate for the exposure that is to be made. The voltage is controlled by the autotransformer. It may be measured by a primary voltmeter, so that the controls are adjusted until the desired voltmeter reading or setting is obtained (Expts. 1 and 3). If the equipment does not include a primary voltmeter, then the primary voltage must be adjusted to the control settings that will give the proper measurement. Without a voltmeter, the best results will be

obtained by testing the spark gap before each exposure. To obtain the correct milliamperage the filament regulator is adjusted to give a particular amperemeter reading, or to a certain position on the regulator scale (Expt. 2).

Next, place the cassette under the part of the patient to be examined and the Roentgen-ray tube over it. The distance of the tube anode from the film should always be carefully measured. The size of the film, the size of the cone in the tube stand, and the distance, all depend on the type of work that is being done. Just after the film has been placed is a good time to give the necessary instructions to the patient. When all is ready, set the automatic timer for the correct time and make the exposure. Correction of the milliamperage by means of the filament regulator after the exposure has started often is necessary. Finally, if the machine is so equipped, open the pole-changing switch; then proceed with the next exposure or stop the machine.

A Roentgen-ray machine requires constant care. It should be kept clean and well oiled. The high-voltage current attracts particles of dust from the atmosphere so that the overhead system, the tube, and the rectifier are soon covered with a thick coating of dust. If this is not removed, it is apt to cause a current leak or a short circuit along insulating brackets, insulators, around the edge of a rectifying disk or along the shaft of a cross-arm rectifier. Since dust will cause fluctuations in the filament current with resulting variations in milliamperage through the tube, and will make a tube more apt to puncture, the filament wires and the tube should be kept clean. In localities where the air is very smoky or dusty, it may be necessary to clean the entire apparatus each day.

Oiling is also important. The motor of the rectifier should be oiled at least once a month. At the same time, the commutator may be cleaned and the brushes inspected. Parts of the equipment where metal rubs against metal should also be oiled occasionally. If the nickeled parts of the machine are rubbed with an oiled rag, it prevents corrosion and rusting of the metal.

If a Roentgen-ray machine is kept clean and well oiled, it will last and give good service for years.

DANGERS.

There are three dangers constantly present in a Roentgen-ray laboratory. One of these is the overexposure of patients with

Roentgen-rays producing some degree of radiodermatitis; another is the liability of operators of Roentgen-ray machines to injuries of the superficial tissues and derangements of internal organs, especially changes in the blood from long-continued exposure to small amounts of Roentgen-rays, and the third is the danger from electric shocks to operators, spectators, and patients.

Overexposures in diagnostic work are so uncommon that many liability insurance companies do not require a physician to pay an extra premium for liability protection, unless treatments are given. In investigating the question of erythema doses with diagnostic voltages, Erskine found, with the tube anode 10 inches from the patient's skin, that a slight redness would be produced by an exposure of 800 milliampere-seconds using 1 millimeter of aluminum as filter and a voltage of 60 average kilovolts or a 5-inch spark gap, and that twice that exposure did not produce much more skin reaction. The distance used in his experiments was very short for diagnostic exposures, the voltage was higher than usually used, so that a limit of 1000 to 1200 milliampere-seconds to one area of patient's skin would be safe for all diagnostic exposures. In such work the chief dangers are in operating an equipment without a filter, which should never be done, and in repeating an examination requiring multiple exposures. To be sure that an overexposure due to the latter cause is not administered, before beginning each such examination, it is best to establish a habit of making a careful inquiry about all preceding Roentgen-ray examinations, and not to repeat one until all effects of the last have subsided.

The deleterious effects from long-continued exposures to small amounts of Roentgen-rays come on without warning and should be carefully guarded against. While there is very little probability of injury of one who does a small amount of Roentgen-ray work, for one who is constantly engaged the danger is real and should be guarded against from the beginning. The recommendations of the different committees that have investigated this subject have been published so often that it is not necessary to repeat them. Those of the Council on Physical Therapy of the American Medical Association were published in the *Journal of the American Medical Association.*

The danger from electric shocks is constantly present. A serious electric shock may result from contact with or too close proximity to any part of the high-voltage or secondary circuit. Since this current will jump an air space that is one-half the spark gap length,

even with the middle of the transformer grounded, and the full length of the spark gap when the transformer is not grounded, actual contact with the wires or tubing is not necessary. To prevent electric shocks, the operator of a Roentgen-ray machine should know when and where such shocks may occur, and always be on guard against them. With a machine equipped with an overhead system, the milliamperemeter, the filament amperemeter, and the wires from the overhead to the tube are the parts of the machine from which shocks usually come. A machine with a low position of the secondary circuit, either of the unit or interrupterless types, is more dangerous than one with an overhead system.

To prevent accidental electric shocks there are certain precautions that should be observed. If these are practiced at the beginning of Roentgen-ray work, they soon become a matter of habit and are repeated automatically and often unconsciously. Perhaps the most important of these is deliberateness. While a very rapid exposure often is advisable, hurrying in a Roentgen-ray laboratory is never necessary. There are so many factors in a Roentgen-ray exposure that enough time should be taken to think out each step in advance.

A Roentgen-ray laboratory should never be crowded with spectators. Even if the entire family accompanies the patient and each member shows a great deal of interest in the Roentgen-ray examination, it is a good practice never to admit more than one spectator to the laboratory. It is best to place this one person in a chair and caution him to remain seated during the work. Overhead wiring to a fluoroscope is usually on the operator's left, so that visitors during a fluoroscopic examination should always be kept on the operator's right-hand side.

Two persons should never attempt to operate, adjust, repair, or otherwise use or work on a Roentgen-ray machine at the same time. Many accidental electric shocks have been due to violation of this precaution.

Before each Roentgen-ray exposure is begun, an operator should make it an inviolable rule to see that all high-voltage wires are at a safe distance from the patient, the tube stand, other persons in the laboratory, and himself. The tube terminals and wires should be distant from the patient at least twice the length of the spark gap of the current through the tube. It is best to develop a habit of seeing that this precaution is observed as the last act before each exposure is begun.

If the machine has in the primary circuit a main switch, a safety

switch, or a polarity switch that can be opened with the motor running and the filament lighted, the maximum degree of safety can be assured if this switch is closed only during actual Roentgen-ray exposures. This is especially true when an examination is being made requiring multiple exposures and considerable adjustment of the tube. In operating a machine so equipped, a habit can easily be formed of closing this switch just before an exposure begins and opening it just after one is completed.

SELECTING A ROENTGEN-RAY EQUIPMENT.

Physicians living in smaller communities so often seek advice as to the kind of equipment that will enable them to do Roentgen-ray work in their own practice and that of other physicians living in the same locality that this question will be briefly discussed.

The kind of Roentgen-ray work that is to be done should be the chief consideration governing the selection of an equipment. In this connection it must be emphasized that if a physician installs a machine, many people will think that he is at once a competent roentgenologist. He will have opportunities of doing Roentgen-ray work of all kinds. If his equipment is inadequate, he must either refuse some of it, or try to do it with insufficient apparatus. If a physician has an inadequate equipment, under such circumstances, he does his work under a serious handicap and often attempts to do the impossible.

The unit type of machine is adequate for simple fluoroscopy and for exposing films of injuries to the extremities, and with the aid of a Potter-Bucky diaphragm, for films of the axial skeleton. It is not large enough for the rapid exposures that are necessary in gastro-intestinal and thoracic roentgenography. For the simpler kinds of work, as in an industrial practice, the unit type of machine with a limited equipment of developing tank, intensifying screens, developing hangers, etc., is adequate.

However, if all kinds of Roentgen-ray work are to be attempted, a larger machine and more complete equipment is necessary. This should include at least an interrupterless type of transformer producing rectified current with a capacity of 98 peak kilovolts, equivalent to a 6-inch spark gap, and 60 milliamperes; a small vertical fluoroscope, a tube stand, two Roentgen-ray tubes, and a Potter-Bucky diaphragm. A tilt-table, permitting both vertical and horizontal fluoroscopy, is even better than a fluoroscope. A hand

even with the middle of the transformer grounded, and the full length of the spark gap when the transformer is not grounded, actual contact with the wires or tubing is not necessary. To prevent electric shocks, the operator of a Roentgen-ray machine should know when and where such shocks may occur, and always be on guard against them. With a machine equipped with an overhead system, the milliamperemeter, the filament amperemeter, and the wires from the overhead to the tube are the parts of the machine from which shocks usually come. A machine with a low position of the secondary circuit, either of the unit or interrupterless types, is more dangerous than one with an overhead system.

To prevent accidental electric shocks there are certain precautions that should be observed. If these are practiced at the beginning of Roentgen-ray work, they soon become a matter of habit and are repeated automatically and often unconsciously. Perhaps the most important of these is deliberateness. While a very rapid exposure often is advisable, hurrying in a Roentgen-ray laboratory is never necessary. There are so many factors in a Roentgen-ray exposure that enough time should be taken to think out each step in advance.

A Roentgen-ray laboratory should never be crowded with spectators. Even if the entire family accompanies the patient and each member shows a great deal of interest in the Roentgen-ray examination, it is a good practice never to admit more than one spectator to the laboratory. It is best to place this one person in a chair and caution him to remain seated during the work. Overhead wiring to a fluoroscope is usually on the operator's left, so that visitors during a fluoroscopic examination should always be kept on the operator's right-hand side.

Two persons should never attempt to operate, adjust, repair, or otherwise use or work on a Roentgen-ray machine at the same time. Many accidental electric shocks have been due to violation of this precaution.

Before each Roentgen-ray exposure is begun, an operator should make it an inviolable rule to see that all high-voltage wires are at a safe distance from the patient, the tube stand, other persons in the laboratory, and himself. The tube terminals and wires should be distant from the patient at least twice the length of the spark gap of the current through the tube. It is best to develop a habit of seeing that this precaution is observed as the last act before each exposure is begun.

If the machine has in the primary circuit a main switch, a safety

switch, or a polarity switch that can be opened with the motor running and the filament lighted, the maximum degree of safety can be assured if this switch is closed only during actual Roentgen-ray exposures. This is especially true when an examination is being made requiring multiple exposures and considerable adjustment of the tube. In operating a machine so equipped, a habit can easily be formed of closing this switch just before an exposure begins and opening it just after one is completed.

SELECTING A ROENTGEN-RAY EQUIPMENT.

Physicians living in smaller communities so often seek advice as to the kind of equipment that will enable them to do Roentgen-ray work in their own practice and that of other physicians living in the same locality that this question will be briefly discussed.

The kind of Roentgen-ray work that is to be done should be the chief consideration governing the selection of an equipment. In this connection it must be emphasized that if a physician installs a machine, many people will think that he is at once a competent roentgenologist. He will have opportunities of doing Roentgen-ray work of all kinds. If his equipment is inadequate, he must either refuse some of it, or try to do it with insufficient apparatus. If a physician has an inadequate equipment, under such circumstances, he does his work under a serious handicap and often attempts to do the impossible.

The unit type of machine is adequate for simple fluoroscopy and for exposing films of injuries to the extremities, and with the aid of a Potter-Bucky diaphragm, for films of the axial skeleton. It is not large enough for the rapid exposures that are necessary in gastro-intestinal and thoracic roentgenography. For the simpler kinds of work, as in an industrial practice, the unit type of machine with a limited equipment of developing tank, intensifying screens, developing hangers, etc., is adequate.

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fluoroscope or a makeshift apparatus with a fluoroscopic screen suspended on pulleys, using the Roentgen-rays from a tube in a tube stand, is unsatisfactory and not without considerable danger. An automatic timing device for timing exposures is most helpful. The installation should include an overhead system of wires or tubing to carry the high-voltage current from the transformer to the tube stand and fluoroscope. To assist in making exposures, a full set of cassettes with double intensifying screens is essential. This should include at least one of each size. If stereoscopic films are to be made, there should be two of each, except possibly the 8- by 10-inch size.

The dark-room equipment should include a developing tank with whatever attachments and accessories are necessary for the maintenance of the proper temperature during the development of films. Often this includes a refrigerator for storing ice. In addition to the tank, there should be a loading bench, a full assortment of developing hangers, a drying rack, thermometer, timing clock, and a lead-lined box or film safe for unexposed films.

While not absolutely essential, the apparatus necessary for exposing and examining stereoscopic films, such as a vertical plate changer, a plate-changing tunnel, and a stereoscope, will be very useful. The best quality of work requires stereoscopic films of certain regions of the body.

Excluding the equipment for stereoscopic films, the cost of an outfit such as outlined will be approximately $3000.

TROUBLE HUNTING.

Breakdowns of a Roentgen-ray machine, causing annoyances and interruptions in service, are rather common. Fortunately most of these are of little consequence, and if detected, can be repaired in a short time. They are most often caused by either a short circuit—two bare wires touching each other—a loose or broken connection, or a blown fuse. Since expert service men are not always available, it is advisable for each operator to be able to locate and remedy all minor troubles.

To do this, some knowledge of the wiring of the machine is necessary. This should include the primary circuit from the supply line switch to the Roentgen-ray transformer, the motor circuit from the supply line to the motor, the circuits energizing the magnetic Roentgen-ray switch, and the filament circuit from the supply line through the filament regulator and transformer to the cathode

filament. The fuses for these different circuits usually are located together on a special board in the control cabinet or panel, and are often labeled so that those for the different circuits can be identified.

A short circuit in any of these lines, except the 12-volt filament line, will cause a flash with some corrosion and heating of the metal of the wires and will blow a fuse. The blown fuse will be slightly heated, a fact that enables it to be located easily if looked for immediately after the accident. If the fuse is replaced and the current again turned on before the short circuit has been repaired, another blown fuse will result.

Occasionally a fuse will be blown from a temporary overload without a short circuit. Blown fuses can be detected by the heating of the fuse, or by means of a test-lamp. A test-lamp for use on a machine receiving a 220-volt current should have a 220-volt bulb. Such a bulb will light to full brilliancy at 220 volts, and to approximately one-half that with a current of 110 volts. If a current of 220 volts is sent through a bulb of smaller capacity, the filament will be melted.

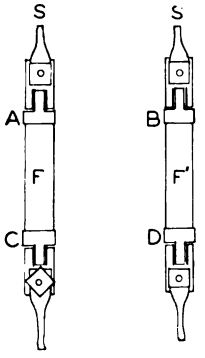

FIG. 26.—A diagram illustrating the method of testing fuses with a test-lamp. The explanation is given in the text.

The method of using a test-lamp can be explained by referring to the diagram in Fig. 26. S represents the lines leading from the supply line and F and F′ are the fuses. If the test-lamp lights when connected across A and B, it indicates that current is reaching that point. If the lamp lights when connected between C and D, the fuses are intact; if it does not light, then one or both of the fuses have been blown. By then connecting the lamp between A and D and between B and C, the trouble can be located. If neither of these connections causes the lamp to light, then both fuses are bad;

if it lights when connected between A and D and does not when connected between B and C, then fuse F has been blown. If fuse F′ is bad, the lamp will not light when connected across A and D.

A loose or broken connection in the primary circuit is very uncommon. A loose connection will cause fluctuations in both the voltage and milliamperage of the Roentgen-ray circuit. With a break in the primary circuit there will be no high-voltage current at all. A loose connection is always accompanied by some sparking, which will heat the wires and attachments near it, and will very often melt the wires, completely breaking the circuit. A loose connection can usually be found if the current is turned on for some time, then shut off and the wiring carefully gone over for a heated place.

A broken connection in the primary circuit is much more difficult to find. It is first necessary to know that the Roentgen-ray switch is in good working order. If this be true, then connect a test-lamp between the wires of the primary circuit at the place they enter the Roentgen-ray transformer. An attempt to energize the tube in the usual way will show by the lighting of the lamp whether current is passing through the primary circuit. If the lamp does not light, there is a break in the circuit; if it lights, the trouble is elsewhere. In case a break is indicated, then it becomes necessary to go over the primary wiring with the test-lamp, test all the connections, and make a thorough search for the break.

Breaks in a circuit energizing a magnetic Roentgen-ray switch are probably next to the most common kind of trouble with a Roentgen-ray machine. These are usually due to a break in the wires at or near their connection to a foot switch, a hand switch, or a hand timer. At these places the wires frequently are bent, which causes one or the other of them to be broken slowly in two. Many magnetic switches have more than one circuit energizing the magnet, so that if one does not function and the others do, the trouble can easily be located.

Trouble in the motor circuit may be due to a blown fuse, worn-out brushes, brushes that make poor contact with the commutator, or occasionally to a burnt-out centrifugal switch in the starting circuit of the motor. The brushes in a motor so equipped should be periodically inspected to see that they are in good condition and making good contact. At the same time it is wise to clean the commutator with a cloth dampened with kerosene, or smooth it off with a piece of fine sandpaper. A bad centrifugal switch must be replaced. In case the polarity indicator fails to register, the trouble most often is caused by an accumulation of débris on the polarity

commutator so that the brushes make poor contact. Cleaning the commutator and the brushes remedies the trouble.

Loose connections or breaks in the filament circuit are the most common form of trouble with Roentgen-ray machines, and easily form more than one-half of such difficulties. A loose connection will cause a marked variation in the milliamperage through the tube; a broken connection will keep the filament from lighting. These troubles may be in the circuit between the supply line and the filament transformer, but most of them are between the transformer and the Roentgen-ray tube. With the filament circuit turned on, if a spark can be obtained at the place where the secondary of the filament transformer leaves it, either by touching the wires together or by making a short circuit between them with a piece of copper wire, then the trouble is between the transformer and the tube. Since this current is of low voltage, there is no danger of getting even an unpleasant shock from it, but the operator must be quite certain that the high-voltage current is off.

Trouble in the primary of the filament circuit should be looked for in the same manner as in the primary circuit. That between the transformer and the tube may be sought by testing the wires by means of a spark between them. If a short circuit is made between the reels and a spark does or does not occur, it at once becomes apparent whether the break is between the transformer and the reels or between the reels and the tube. If in front of the reels, the most probable place is in an overhead switch. Most often breaks are in the wires leading to the filament connector at the cathode end of the tube. At this place the wires often are bent and always are taut, making them more likely to break here than elsewhere.

Fluctuations of major extent in the milliamperage through the Roentgen-ray tube indicate a loose connection in the filament circuit. To locate such trouble Horsley recommends that the filament be lighted to full brilliancy, without energizing the tube, and left on for some time. Then by searching the entire circuit, cathode connector, reels, overhead switches, etc., for a warm place in the wires or tubing, the loose connection can be located.

Short circuits from the high-voltage lines to a water pipe, an electric wire, or to a grounded apparatus occasionally occur. They are most often due to a sagging wire in a defective reel or to a defective insulator. Trouble in either the Roentgen-ray or filament transformer causes heating of the transformer so that the expanding oil may flow out at the top. Such troubles are always of major importance and require the services of an expert service man.

When properly used, a Coolidge tube rarely develops defects that cause trouble. With use, the glass of the bulb may become purple and the anode slightly pitted, neither of which interferes with the proper functioning of the tube. A marked amount of pitting, especially if part of the focal spot has been melted and cooled in droplets on the anode face, may interfere with the Roentgen-ray output from the tube. If too heavy currents are used, pitting of the anode becomes quite marked, the tungsten usually volatilizing and settling on the inside of the bulb in a black, mirror-like deposit which makes the tube more liable to puncture. A slight greenish fluorescence in the anode arm of a Coolidge tube is usually present when the tube is in operation. A greenish, bluish, or pinkish light in any other part of the tube indicates that it has become gassy. It is best to return such tubes to the factory for examination. An attempt to operate one that has been punctured or that is very gassy will burn out the filament and increase the cost of repairs.

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CHAPTER IV.

ROENTGEN- OR *X*-RAYS.

THE NATURE OF ROENTGEN-RAYS.

THE luminiferous ether is a hypothetical substance believed to fill the spaces between and within the atoms of the gases of the atmosphere and those of opaque and solid substances. It is spoken of as luminiferous because it transmits light. At one time visible light was believed to be produced by vibrations of particles in this ether. At present it is believed that light is produced by variations in the electric and magnetic intensities in it.[1] These variations occur at regular intervals which give to them a form of wave motion.

If a beam of white light be passed through a slit and then through a prism, it will be separated into various colors—those that compose the spectrum. This separation into colors is brought about by the segregation into certain regions of those light waves which have similar wave-lengths, wave-lengths within certain limits producing the sensation of color when striking the retina.

The wave-lengths of many forms of electromagnetic wave motion are so short that a special unit of measurement has been devised for them by a Swedish physicist named Angström. This is now known as an Angström unit, which may be abbreviated to A.U. One Angström unit is one hundred-millionth of a centimeter, or 0.00000001 cm. The shortest waves of visible light are those of violet, which have a wave-length of 3920 A.U.; the longest visible light waves are those of red, with a wave-length of 7000 A.U. Only those electromagnetic waves between 3920 and 7000 A.U. produce an effect on the human retina.

There are other forms of electromagnetic wave motion with both longer and shorter waves than those of visible light. Infra-red rays, of longer wave-length than the red rays of the visible spectrum, and perceptible chiefly as heat, are now being used for therapeutic purposes. Ultra-violet rays, shorter than the shortest violet of the

[1] It is realized that this is a disputed point. It is thought best to give the more generally accepted idea as an established fact rather than attempt a discussion of both sides of the question.

visible spectrum, are also used therapeutically. Wireless and other electrical waves, with wave-lengths of several hundred meters, are of the same physical nature as light waves, differing chiefly in wave-lengths.

To the same order of physical phenomena belong Roentgen-rays or *x*-rays. Those Roentgen-rays that are useful in roentgenology have wave-lengths extending from about 0.4 to 0.06 A.U.; those useful in roentgenography probably are never shorter than 0.12 A.U., the shorter rays being used only for Roentgen therapy. While Roentgen-rays as long as 500 A.U. and as short as 0.003 A.U. have been produced experimentally, at present they are not useful rays.

As stated in the introduction to the preceding chapter, Roentgen-rays are produced by the passage of a high-voltage low-amperage electric current through a Roentgen-ray tube. The passage of the current depends on the presence of electrons in the tube. In a gas tube the electrons which carry the current are provided by the gases that remain in it. Because of the more complete exhaustion of the Coolidge tube, this source of electron supply is not available and another is provided.

Before the development of the Coolidge tube it had been shown that heated metals give off electrons. This was made use of by Coolidge in the development of the tube that bears his name. He made the cathode of the tube a spiral of tungsten wire that could be heated by a storage battery or a low-voltage alternating current. In a Coolidge tube it is, therefore, the heated tungsten wire of the cathode filament that provides the electrons necessary to carry the high-voltage current through the tube.

When such current is sent through a Roentgen-ray tube, the electrons passing from the cathode to the anode or target are propelled at great speed; a speed as great as one-third the velocity of light has been noted. When electrons traveling at such velocity are suddenly interrupted in their course by striking a solid object, the greater part of the energy of the electron stream is changed into heat, but a part of it creates electromagnetic waves which travel out in all directions with the speed of light. Electromagnetic waves so produced are Roentgen-rays.

The speed with which the electrons are passing at the time of their sudden interruption determines the wave-lengths of the resulting Roentgen-rays. The voltage of the current through the tube provides the electrons with their velocity. Those traveling at the greatest speed, impelled by highest voltages, produce the shortest

wave-lengths. Therefore, the voltage of the current through the tube is a measure or a method of indicating the wave-length or quality of the rays produced.

It is impossible to produce a Roentgen-ray beam that is composed of waves all of the same length. In the interrupterless type of Roentgen-ray machine the voltage is never constant. The alternating high-voltage current is partially rectified by the rectifier, the amount of rectification probably depending somewhat on the design of the rectifier. If it is assumed that one-half of the current of a voltage of 60 kilovolts is rectified, then during each half-cycle the voltage variation extends from 30 to 60 and back to 30 kilovolts. Roentgen-rays corresponding to all these voltage variations will be produced.

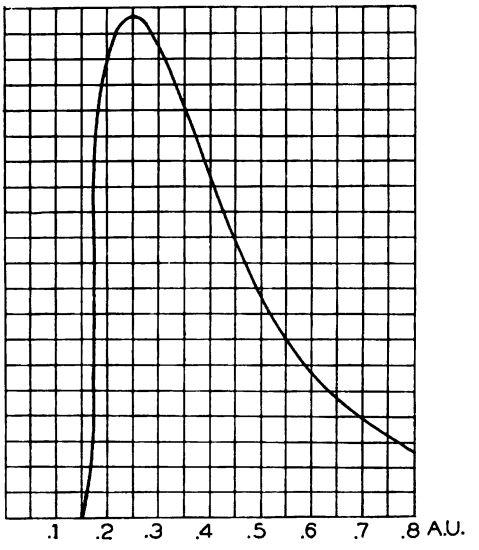

FIG. 27.—Wave-lengths produced by 70 kilovolts. (From Shearer.)

There is no advantage in rectifying and using voltages of less than approximately 42 peak kilovolts. The Roentgen-rays produced by them would all be of long wave-lengths and not sufficiently penetrating to pass through the glass wall of the tube and the aluminum filter in their path. If the voltage of the current be increased in progressive steps from this minimum, Roentgen-rays of shorter and shorter wave-lengths will be added to the resultant beam. Fig. 27 shows graphically the distribution of the different wave-lengths in a

beam produced by a current of 70 kilovolts (Shearer). The shortest rays are 0.15 A.U. in length. These are few in number. The predominant wave-length is in the neighborhood of 0.3 A.U. The longest are over 0.8 A.U. in length. Kaye gives a table of the shortest wave-lengths produced by different voltages from 10 to 300 peak kilovolts. Within the range of voltages useful in roentgenography, these are given in the following table:

TABLE I.

Kilovolts (peak)	Shortest wave-lengths in A.U.
30	0.413
40	0.310
50	0.248
60	0.207
70	0.177
80	0.155
90	0.138
100	0.124
110	0.113
120	0.103

Even if the voltage of the current could be kept absolutely constant, a heterogeneous beam would still result. The irregularities of the anode or target surface cause some deflection of the electrons from one part to another, producing a wave of different length at each impact.

While the quality (wave-lengths) of Roentgen-rays depends on the voltage of the current sent through a Roentgen-ray tube, the amount, number, quantity, or intensity of rays in a unit of time is directly proportional to the milliamperage, as measured by the milliamperemeter. Inasmuch as the current (measured in milliamperes) is carried from the cathode to the anode by electrons, the quantity of rays also depends on the number of electrons given off by the heated filament. If the heat of the filament comes from the electric current in the filament circuit, then the quantity of rays also depends on the filament current, as measured by the filament amperemeter.

From this it may be seen that the quantity of rays may be indicated in one of two ways: by the amperage in the filament circuit, and by the milliamperage of the high-voltage circuit. The filament current necessary to produce a given heat, and consequently a given number of electrons, is not the same in all Coolidge tubes, nor is it the same at all voltages in any one tube. For this reason, the milliamperage of the high-voltage current through the tube is

the satisfactory electrical indication of the quantity of the resultant rays.

There are ways in which the quality and quantity of a Roentgen-ray beam may be directly measured, but none of them are practical for ordinary purposes. All are so complicated that extra equipment and special training in physics are necessary for accurate results. For this reason they are not in common use. Therefore, the quantity and quality of Roentgen-rays in most laboratories are measured and spoken of in terms of the electric current used in their production: the voltage of the current as an indicator of quality, and the milliamperage of the current with the time of the exposure as a measure of the quantity.

As previously stated, the voltage may be spoken of as measured by a spark gap in inches or centimeters, as average or effective kilovolts, or as peak kilovolts. By multiplying one by the other, the milliamperes and the time may be combined as milliampere-seconds. Thus, 20 milliamperes for five seconds would be 100 milliampere-seconds; 50 milliamperes for two seconds would be 100 milliampere-seconds; 10 milliamperes for one second would be 10 milliampere-seconds; 40 milliamperes for one-quarter second or 100 milliamperes for one-tenth second would be 10 milliampere-seconds, etc. In a similar manner, for long exposures, as in treatment, the milliamperes may be multiplied by the time in minutes, producing milliampere-minutes.

GENERAL PROPERTIES OF ROENTGEN-RAYS.

The usefulness of Roentgen-rays in the practice of medicine depends on a few general properties. In Roentgen diagnosis these are:

1. The ability of Roentgen-rays to penetrate some objects and substances opaque to ordinary light.
2. The ability of Roentgen-rays to affect a photographic emulsion.
3. The ability of Roentgen-rays to cause fluorescence of certain crystals.

In addition, Roentgen-rays have very important biological effects upon which depends their usefulness in Roentgen therapy, and they possess the power of ionizing gases, a property used in the accurate measurements of intensities of exposures in treatment.

The Penetrating Power of Roentgen-rays.—The penetrability of a substance by Roentgen-rays depends on the nature of the substance, its thickness, and the quality of the rays attempting to pass through

it. For different substances of the same thickness the penetrability is directly proportional to the density. Gases, for instance, have little resistance to the passage of Roentgen-rays through them. Aqueous liquids, being of greater density, are less easily penetrated. Still denser substances, such as the heavy metals, either in sheets or in solutions of their salts, are more opaque. A certain depth of weak solution of a salt of a metal would be less dense and therefore more penetrable than a similar depth of a stronger solution.

In addition to the density, the penetrability also depends on the thickness of the substance and the quality of the rays. Rays of a particular quality may easily penetrate a certain thickness, and all be absorbed by a greater thickness of the same substance. This may be illustrated by an example from medical roentgenography. Rays just penetrating enough to pass through a thin part, such as the hand, would all be absorbed by a thicker part, such as the hip. While in thin sheets the denser metals may not be opaque to average Roentgen-rays, in thicker masses the opacity may be complete. Even this is relative, for Roentgen-rays are now being used to detect flaws and defects in relatively thick masses of brass, steel, etc.

The penetrating power of Roentgen-rays depends on their wave-lengths—the shorter the rays the greater the penetrability. Since the wave-lengths are determined by the voltage of the current producing the rays, penetrability may be determined and expressed in terms of voltage. This makes it possible, without making an actual determination of the wave-lengths, to indicate a certain quality of rays, both in wave-lengths and in penetrability, by mentioning the voltage at which they were produced. While it is but a rough measure of quality, this is the common and usual practice in roentgenography.

The Effect of Roentgen-rays on a Photographic Emulsion.—The second important property of Roentgen-rays is their ability to affect a photographic emulsion in a manner similar to visible light. A photographic emulsion is made of a preparation of silver suspended in an emulsion of gelatin and spread in a thin layer on some form of support. If on a sheet of glass, a plate is made; if on a transparent celluloid-like base, a film is the result. The most useful and most common form of photographic material for roentgenography is a film with the emulsion in layers of similar thickness on both sides of the support. This is called a double-coated film.

The change which takes place in a photographic emulsion when struck by light or Roentgen-rays is so slight that it cannot be seen

or measured by chemical or physical means. It does not become apparent until the emulsion is put into a reducing solution known as a developer. In this, the affected silver is reduced to a metallic state, which forms in minute black granules, invisible to the unaided eye, held in position by the surrounding gelatin. Unaffected silver in the emulsion remains unchanged and must be removed. This is done by immersing the film in a second solution, known as a fixing bath or fixer, in which the unchanged silver is dissolved from the emulsion.

The processes through which it is put, after exposure, are collectively known as the development of the film. When properly carried out, the final result is a clear, clean, transparent film with the image on it produced by the arrangement of the minute granules of metallic silver in the gelatin.

The Fluorescent Action of Roentgen-rays.—The third important property of Roentgen-rays is their ability to cause fluorescence of certain crystals. When a substance fluoresces, it gives off visible light. If caused by Roentgen-rays, the rays themselves are invisible, but the fluorescent bluish-white light can be seen. Fluorescence of this sort was one of the phenomena that attracted the attention of Professor Roentgen, and which led to the discovery of Roentgen-rays.

Fluoroscopic screens and intensifying screens are made of calcium tungstate, a substance that fluoresces when Roentgen-rays strike it. Crystals of this material are carefully purified, finely ground, incorporated with some binding substance, and spread in a layer of uniform thickness on cardboard or other support. The fluoroscopic screen is covered with a piece of lead glass and mounted in a frame. Fluorescence of the screen can be seen through the lead glass, but the rays causing the fluorescence are stopped by it.

An intensifying screen is made to be placed in intimate contact with a photographic emulsion during a Roentgen-ray exposure. When this is done, the effect on the emulsion is twofold: that of the Roentgen-rays which strike the emulsion, and that of the fluorescence from the screen. In this way a smaller quantity of Roentgen-rays is required to produce a certain effect on the emulsion than if the screen had not been used.

To further reduce the quantity of Roentgen-rays necessary to produce a certain photographic effect on a film, use is made of double-coated films and double intensifying screens. The screens are mounted with their fluorescent surfaces facing each other in an

apparatus known as a cassette. If a double-coated film is placed in a cassette and the cover closed, the screens are in intimate contact with the emulsion on the film. When exposed, the effect of the Roentgen-rays is not more than an eighth of the total, the greater part being caused by the fluorescence of the screens. It may be said, therefore, that, within the range of voltages used in roentgenographic work, the Roentgen-rays are used to excite fluorescence of the screens, and that it is the light from them that produces the effect on the film.

INTENSIFYING SCREENS.

Double intensifying screens of good quality, properly mounted in suitable cassettes, are a very important part of a modern Roentgen-ray equipment. Quality in screens includes freedom from grain and afterglow, and uniformity in speed. Graininess is caused by large crystals of the fluorescent salt in the screens. Afterglow means a continuation of the fluorescence after an exposure has stopped. If it continues for a sufficient time, it may be enough to cause an image on an unexposed film placed in a cassette immediately after an exposed film has been removed. Screens of uniform speed are such that different ones will give the same photographic effect with the same Roentgen-ray exposure. Modern manufacturing methods have largely eliminated grain, afterglow, and irregularities in speed from intensifying screens.

The initial mounting of intensifying screens in cassettes should be done with considerable care. To hold the screens in place, thin adhesive tape or rubber cement should be used. Some manufacturers supply a suitable adhesive tape with the screens. Water-soluble glue should never be used, for it will penetrate the backs of the screens and make a hard, inflexible spot on the fluorescent surfaces. Only a good quality of wool felt, free from foreign material, should be used as padding.

Cassettes should be constructed and the screens mounted in them in such a way that there is absolute contact between the screens and the emulsion of the films over their entire surfaces. If contact between screens and films is imperfect, the fluorescence from the screens is not limited in its action on the emulsion to an area of the same size as the one from which it originates, but covers a larger area. Images on films exposed in cassettes with poor contact have a blurred appearance which may be spread over the entire film or limited to one or more smaller areas. If films have such an appear-

ance and movements during exposures can be excluded, poor contact between screens and films should be suspected.

Imperfect contact between screens and films is a rather common cause of poor quality in Roentgen-ray films. To test cassettes for contact, secure a piece of wire meshing, with meshes from $\frac{1}{4}$ to $\frac{1}{2}$ inch in diameter, and large enough to cover the largest size of cassette. Lay the wire on the cassette and expose a film through it. A 3-inch spark gap (57 peak kilovolts), 30 milliamperes for one-half second, at a 35-inch distance, is a satisfactory exposure. When a film so exposed has been developed, if the image of the wire is distinct over the whole film, the contact between film and screens is good. If there is blurring of the images of the wire in any part

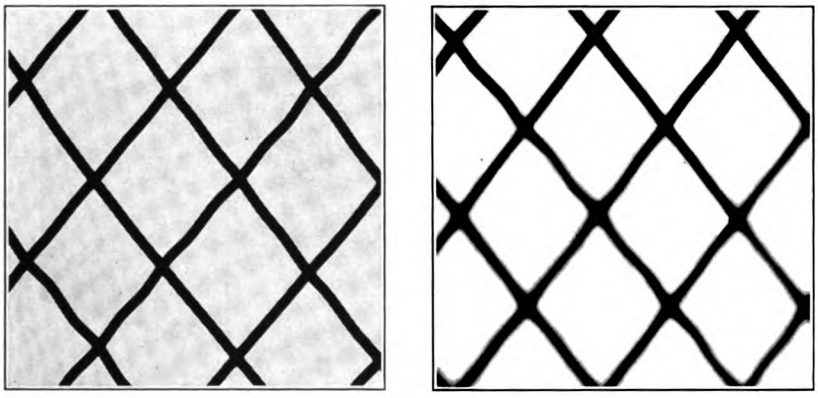

FIG. 28.—The image of a wire screen showing good and poor contact of intensifying screens and film. (Eastman Kodak Company.)

of the film, contact at that place is poor and should be corrected (Fig. 28).

This can be done by building up with paper the areas where contact is deficient. Cut out a series of pieces of paper, diminishing in size from a large piece that covers the whole area of poor contact to a small one, all of approximately the same shape. Fasten these together with glue or paste (Fig. 29). When finished, place this under the screen on the lid of the cassette next to the felt pad. This will build up the low area and restore contact.

Cassettes may be dropped or subjected to other rough handling sufficient to change their shape and the contact of the screens. To guard against this they should be tested periodically for contact as outlined above and the defects corrected.

The useful life of intensifying screens depends largely on the care they receive. They should be kept as free from dust as possible. Organic material such as finger prints, lint from the felt padding, etc., should be removed by dusting with a camel's hair brush or a silk duster and by washing with cotton and Ivory soap. Metallic particles from cassettes or developing hangers become imbedded in the screens, and even after removal leave minute permanent defects. Developing solutions do no damage if immediately washed off; if permitted to dry on the screens, they leave permanent defects. Such defects produce spots on all films afterward exposed with the

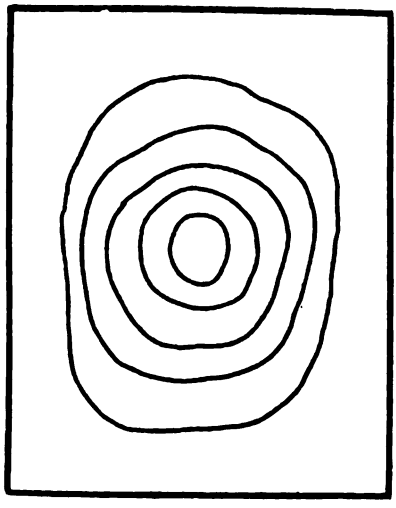

FIG. 29.—Showing a method of making paper pads for building up places of poor contact in intensifying screens and cassettes (Eastman Kodak Company.)

screens. False images on films caused by screen defects sometimes make interpretation difficult. When defects in screens become so numerous as to seriously reduce the quality of films exposed with them, the screens must be discarded and new ones purchased.

In mounting and caring for intensifying screens, it is always best to follow the instructions of the manufacturers.

ROENTGENOGRAPHIC PHENOMENA.

Roentgenography depends on the penetrating power of Roentgen-rays, their ability to affect a photographic emulsion, and their ability to cause fluorescence in crystals. A consideration of the

phenomena which take place when a film of a part of the body is exposed, will illustrate the manner in which use is made of these properties. It must be assumed that a voltage has been selected that will give rays of the proper quality. A cassette, loaded with double intensifying screens and a double-coated film, is placed under the part of the body, the tube is centered and the exposure made.

The beam of Roentgen-rays leaving the tube is composed of all wave-lengths, from those just penetrating enough to pass through the glass wall of the bulb and the filter, to the shortest that can be produced by that particular voltage. Although heterogeneous, consisting of different wave-lengths, experience has taught that the proper quality and quantity of rays are present to give a satisfactory film of that particular part.

Undoubtedly many of the rays will be absorbed or stopped by the superficial layers of tissue, this absorption continuing as the rays penetrate deeper and deeper. It will not be uniform, for the denser portions, such as bone, will absorb a greater proportion of the rays than other tissues. Even the absorption by bone is irregular, denser parts, such as the cortex and trabeculæ, absorbing more than the marrow cavity and the intertrabecular spaces. Those portions of the part around the bone, not being so dense, will not stop so many of the rays. Even here again the absorption will not be uniform, for there are some differences in density in the soft tissues. Muscle masses, tendons, heavy ligaments, etc., are denser than layers of fat and superficial tissues.

Only those rays that reach the intensifying screens and the emulsion of the film will produce an effect on the silver salts, partly through direct action, but mostly through fluorescence of the screens. Since the absorption or stoppage of rays is irregular, the effects of those which pass through are also irregular. Because fewer rays penetrate the denser portions, the fluorescence and direct action will be less under these parts than elsewhere, less of the silver in the emulsion will be affected, so that on the finished film the shadows of these portions will appear the lightest. Images of structures of less density will vary through all gradations from light gray to black. Should the film be larger than the part being examined, the blackest portion will be at the margins where there is nothing to interfere with the rays.

The finished roentgenogram is a pictorial representation of the variations in the density of the structures making up the part of the body which is shown on it. If these differences are marked, as

between bone and flesh, the contrast of the shadows on the film will be distinct. If the differences are slight, as between the kidneys and the surrounding tissues, the shadows on the film will show but little variation in shade. If there is no appreciable difference in density between two structures lying side by side, no differentiation will be shown on the film.

Differences in density occurring naturally are found in many parts of the body. Those shown on films of bones, of the teeth, and of the thorax are examples. When a natural difference in density does not exist, it is often possible to create an artificial variation that answers the same purpose. Many examples of this may be cited. Most common, perhaps, is the addition of barium sulphate to stomach and intestinal contents. Pyelography, cholecystography, the injection of discharging sinuses, pneumoperitoneum, and lipiodol injections into the bronchi and lungs, are all examples of an artificial density especially created for the purpose of registering structures on Roentgen-ray films.

In the preceding paragraphs it has been assumed that in making a roentgenogram all of the rays were either absorbed or passed through the tissues in a direct line. This is not exactly true. Some of the rays which pass through the part are diverted from their paths, and emerge at various angles from their original direction. This is known as scattering, the rays thus diverted being known as scattered rays.

Scattering occurs with all rays and at all depths. It is rather pronounced in animal matter (Kaye). The thicker the substance and the more penetrating the rays, the greater the amount of scattering. Since scattered rays produce an effect on a photographic emulsion similar to direct rays, when scattering is marked, detail and contrast on films may be materially reduced by them.

In roentgenograms of thin parts, scattering interferes but little with the quality of the films. When thick parts are exposed, however, as for example a thick abdomen, scattering is quite marked. There are two methods of reducing the bad effects of scattered radiation. One is by using a small cone or diaphragm and including only a small portion of the body on each film. The other and better method is by using a Potter-Bucky diaphragm.

POTTER-BUCKY DIAPHRAGM.

Reduced to its essential parts a Potter-Bucky diaphragm consists of a grid with some form of mechanism for moving it between the

patient and film while an exposure is being made. The grids are of two forms, curved and flat. The curvature of a curved grid forms part of the arc of a circle, the radius of which is 25 inches. It is made up of alternating thin strips of lead and wood, the ratio of the width of the strips being about 1 of the former to 6 of the latter. The inclination of the lead strips is such that each is placed in the radius of the 25-inch circle. The lead strips of the flat grid have as nearly as possible a similar inclination.

Most often the mechanism for moving the grid is provided by the tension of a strong coiled spring working against the pressure in an oil chamber. The speed is controllable by varying the size of the opening through which the oil must flow. The top of the diaphragm is either curved or flat, depending on the grid, and is made of some material relatively non-opaque to Roentgen-rays but strong enough to support the weight of the patient. Aluminum and bakelite are most often used. Sliding in and out beneath the grid is a pan in which the cassettes with double intensifying screens and films are placed.

When a Potter-Bucky diaphragm is used, the anode of the tube should be placed exactly above the middle of the grid at a distance of 25 inches. When so placed, the rays from the tube will pass directly through the openings between the lead strips. The tube may be centered with reference to the strips in a longitudinal direction either way, but a lateral position much out of this line is not permissible. As will be discussed later, a distance greater than 25 inches between the grid and the tube anode may occasionally be used to advantage.

It is obvious that if the grid moves in the arc of a circle of which the anode of the tube is the center, the spaces between the strips through which the rays may pass are of the same width in all parts of the grid, and in all positions. In a diaphragm with a flat grid the lead strips may be placed so that they are in the radii of a circle with the anode as its center, but if the grid is moved in either direction, this relationship is somewhat disturbed. From this it seems probable that the Potter-Bucky diaphragm with a curved grid is more efficient than one with a flat grid, especially when large films are used.

The usefulness of the Potter-Bucky diaphragm depends on the fact that those rays which are scattered during a Roentgen-ray exposure and which attempt to emerge at an angle with the direct rays from the tube, strike the lead strips of the grid and are stopped

(Fig. 30). By its use as much as 90 per cent of the scattered radiation is absorbed, so that the photographic effect on films so exposed is produced practically entirely by rays that have passed directly through the part being examined. The elimination of scattered radiation in this way markedly improves detail and contrast on the finished films. For this reason, this apparatus is indispensable in making films of thick portions of the body, necessitating penetrating rays produced by a relatively high voltage.

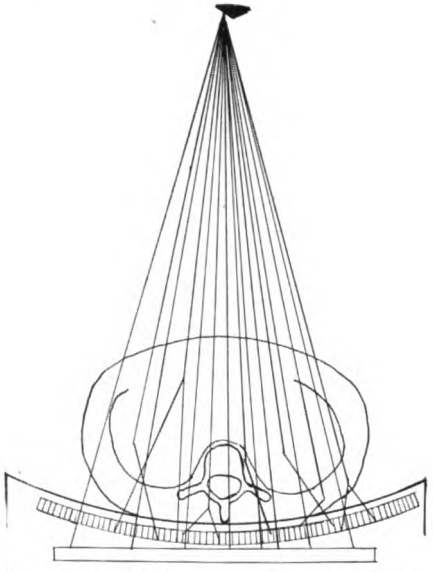

FIG. 30.—Diagram illustrating the absorption of scattered Roentgen-rays by the lead strips of the grid of a Potter-Bucky diaphragm.

To use a Potter-Bucky diaphragm the tube must be centered before the patient is put in position. The film and the patient are then placed with proper relationship to each other. When all is ready the grid must be set in motion before the exposure starts and must continue moving until after the exposure has stopped. If this is not observed carefully or if the movement of the grid is not uniform, the images of the grid strips will be present on the film.

In addition to its cost, the objection to a Potter-Bucky diaphragm is that the absorption by the grid strips necessitates a heavier exposure than is required without it, and that the separation of the patient and film by the grid and top of the diaphragm increases

distortion. Even with these objections, film quality is so much improved by its use that a Roentgen-ray equipment for general purpose diagnostic work should not be without a Potter-Bucky diaphragm.

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CHAPTER V.

DARK-ROOM EQUIPMENT AND TECHNIQUE.

In making roentgenograms, there are two separate and distinct processes. One is the exposure of the films in the Roentgen-ray laboratory, and the other is the treatment of them in the dark room. An incorrect exposure cannot be corrected by dark-room manipulation, but a correct exposure can be spoiled by improper development. Without exact handling of exposed films, it is not possible to detect errors in exposure, and thus correct them. Incorrect exposures may be due to ignorance; improper development is more often due to carelessness.

While it is not intended to enter into a detailed discussion of dark-room construction and equipment, there are certain essentials that must be emphasized. A dark room need not be large, but a closet under a stairway or an unused clothes closet is inadequate. If suitable ventilation can be provided, a dark room 6 by 8 feet in dimensions may be furnished so that it will be suitable for a small Roentgen-ray laboratory. The Eastman Kodak Company has prepared excellent plans for a small dark room which it will furnish on request. All Roentgen-ray sales agencies will provide the same service.

The lighting and ventilation of a dark room are both important. When undeveloped films are being handled, all daylight must be rigorously excluded. By remaining in a dark room with the lights out until the pupils of the eyes have had time to dilate, all light leaks can be detected. Illumination with either red or green lights, if especially constructed for that purpose, and equipped with light bulbs of the size recommended by the manufacturers, is usually safe. For ventilation there should be at least one outside window which can be opened admitting both light and air when the room is not in use. An opaque black shade, best made of automobile top material, working up and down on a shade roller, and moving in a slot between two thin boards projecting from the window frame at the sides and bottom, will, when closed, prevent daylight from entering and will permit opening the shade for outside light and the window for ventilation (Fig. 31).

A dark room should be clean. Usually it is the most poorly kept place on the premises. It should not be used as a storage room, nor should it be littered with discarded films, waste paper and the like. It is almost impossible to keep intensifying screens in good condition in a dirty dark room, especially when the ordinary organic dusts are mixed with chemicals that have been spilled and permitted to dry.

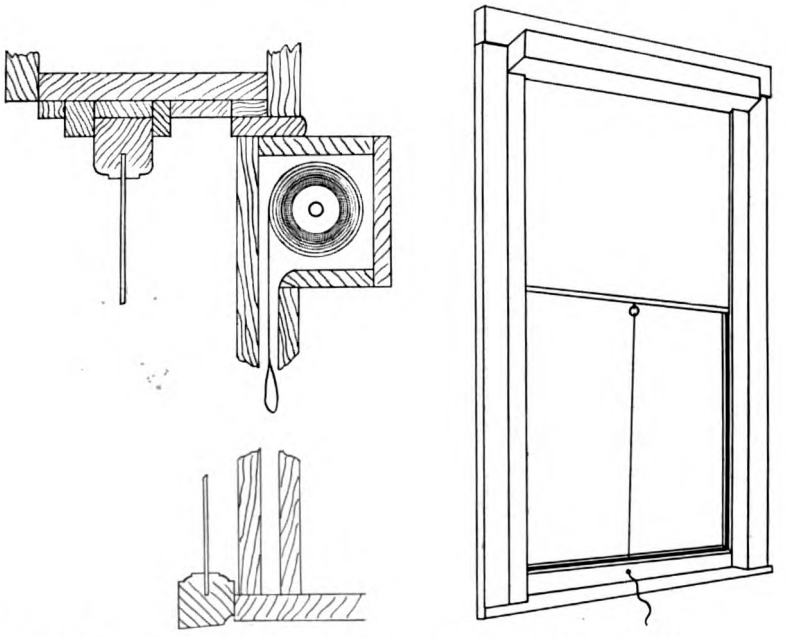

FIG. 31.—Details of the construction of a light-proof shade for dark room or Roentgen-ray room windows. The framework is made of thin boards, the curtain of automobile top material.

The dark-room equipment should include a developing tank, benches for loading and unloading cassettes and exposure holders, a rack for drying films, a lead-covered box or safe for storing unused films, and a suitable assortment of film developing hangers, etc. Tray development is apt to be mussy; the solutions must be discarded after they have been used; it is difficult to maintain a proper temperature of the solutions, and it is much more complicated than tank development. In fact, tray development of Roentgen-ray films should be relegated to the obsolete. If a physician has enough Roentgen-ray work to warrant investment in a Roentgen-ray equipment, a developing tank should be part of it.

A tank made of hard rubber composition material with a 6-gallon compartment in each end, one for developer and one for fixing bath, and a 12-gallon compartment in the middle for washing, is a suitable form. The middle compartment is provided with a running water and a sewer connection. In localities where the solutions must be cooled, a tank such as this may be insulated by covering the sides, ends, and bottom with 3-inch corkboard fastened with asphalt cement, the surface of the cork being covered with a thick coating of

FIG. 32.—A satisfactory arrangement of dark-room equipment including a developing tank, loading bench, film drying rack, film safe, and an assortment of developing hangers. The sink is not shown in the photograph. This dark room also contains the transformer and rectifier to remove the noise of the motor from the Roentgen-ray room. If the developing tank is provided with a light-proof cover, a light lock is unnecessary.

asphalt paint. In hot weather, filling the water compartment with fresh water once a day and cooling it to the required temperature with ice will maintain a proper developing temperature in all compartments and provide adequate facilities for washing. In other climates, where cooling of the solutions in the warmer months is not necessary, the corkboard insulation may not be needed. If warming during the colder months is required, a connection with a hot-water supply may be a distinct advantage.

In the dark room the loading bench should be removed as far as

possible from the developing tank. Splashing of developing or fixing solution on unexposed films will cause defects when they are used. Developer on an intensifying screen, if permitted to dry, will leave a permanent stain that will cause a spot on all films afterward exposed by it.

A suitable drying rack may be made of a piece of 2- by 4-inch studding, with ⅜-inch holes slanting downward in one edge. It may be fastened to the wall or supported by a simple framework. The films are suspended by sticking one end of the cross-bars of the developing holders into the holes. To prevent frilling of the emulsion in a hot, moist atmosphere, and to hasten drying, a current of air from an electric fan often is necessary. Special film driers provided with an electric fan may be purchased.

A lead-lined box or a lead-covered film safe for storing unused films is an essential. A film safe with a compartment for each size of film, preferably for the 6-dozen boxes, provided with a lightproof cover, from which the films may be taken without removing and replacing the lids of the boxes, is a time-saving apparatus. This can be made by any carpenter. The ones on the market are rather expensive and do not make provision for 6½- by 8½-inch films.

Suitable hooks or supports for the developing hangers, a large box for scrap paper and other trash, a sink for washing the hands, and other simple pieces of equipment, add to the ease with which dark-room work may be done and assist in keeping the room clean.

DEVELOPMENT OF FILMS.

For the development of Roentgen-ray films the developer and fixing bath powders prepared and marketed by the manufacturers of photographic supplies are recommended. When made into solutions by following the directions accompanying the packages, chemicals of the proper purity and of the correct amount will be present. Such powders are slightly more expensive than chemicals purchased separately, but the ease and rapidity with which the solutions may be prepared more than offset the slight additional expense. Developing solutions should be made with distilled or clean rain water; tap or well water may be used for the fixing bath.

The change which takes place in the silver salts of a photographic emulsion in a developing solution, by which the silver is reduced to a metallic state, is a chemical reaction. Similar to all chemical reactions, it depends on the temperature, the time the different chemicals

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are permitted to act on each other, and on the strength of the solution. All of this has been carefully taken into account by the manufacturers of the films. They have determined the proper strength of the developing solutions, the time, and the temperature which will give the best films. Deviations from their recommendations will detract from the results and should not be practiced.

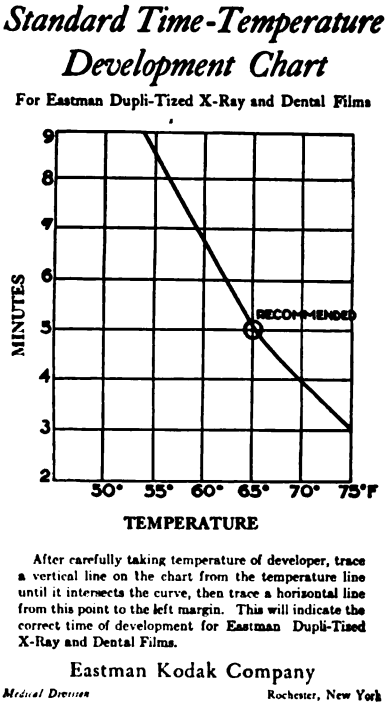
Standard Time-Temperature
Development Chart
For Eastman Dupli-Tized X-Ray and Dental Films
MINUTES
9
8
7
6
5
4
3
2
RECOMMENDED
50° 55° 60° 65° 70° 75°F
TEMPERATURE
After carefully taking temperature of developer, trace a vertical line on the chart from the temperature line until it intersects the curve, then trace a horizontal line from this point to the left margin. This will indicate the correct time of development for Eastman Dupli-Tized X-Ray and Dental Films.
Eastman Kodak Company
Medical Division
Rochester, New York

FIG. 33.—Standard time-temperature development chart. (Eastman Kodak Company.)

The manufacturers have determined that a properly exposed film will develop to its optimum in a certain time at a particular temperature. Five minutes at 65° F. in fresh developer is usually recommended. If the temperature of the solution is either colder or warmer, the time must be changed to correspond. Cooling of the solution slows the reaction; warming hastens it. Fifty-five and 75° F. are the extreme limits at which development may be carried out. The chart (Fig. 33) prepared by the Eastman Kodak

Company shows the time corrections for different temperatures recommended for materials manufactured by it.

Whenever necessary, provision must be made for the maintenance of the correct temperature of the developing solutions. A temperature range of 5°, from 65° to 70° F., is all that should be permitted. The equipment necessary to control the temperature will depend on the climate. In some climates cooling during six months or longer in the summer is the difficulty. This may be met by corkboard insulation of the tank and the use of plenty of ice or by equipping the tank with machinery for electrical refrigeration. In other climates provision must be made for warming in winter, and in yet others both cooling in the summer and warming in the winter may be required.

Developing at a temperature that is too high, above 70° F., will reduce some of the unaffected silver in the emulsion, causing what is known as chemical fog. It will also cause a softening of the gelatin of the emulsion, producing a rough, uneven appearance, known as frilling, or will loosen it from the support. A low temperature retards all chemical reactions, so that a temperature that is too low will prolong unnecessarily the development of films.

The Eastman Kodak Company has perfected a method of processing Roentgen-ray films under hot weather conditions. This method requires an adjustment of the exposures so that development to the correct density is completed in two minutes at temperatures between 80° and 95° F. After development the films are placed in a special hardening solution for three minutes and then transferred to the fixing bath. The solutions need not be cooled below 90° F., and, after fixation, washing may be carried out at a temperature as high as 100° F. This method is not recommended except as a last resort, after all methods of cooling the solutions such as the use of ice, electrical refrigeration, or city water fail. The details of this method may be obtained from the literature of this company.

Time of development is just as important as temperature. If the time is too short, the films will be pale, lacking in contrast and detail. If the time is too long, chemical fog will ensue.

In developing films, the only proper practice is to immerse them in the developer for a time which is regulated by the temperature and strength of the solution. The temperature may be determined at any time from a thermometer kept suspended in one corner of the developing compartment of the tank. A clock that may be set to ring an alarm after a certain number of minutes is very convenient for timing. If a Roentgen-ray exposure has been properly made, the

film may be suspended in the tank, the tank covered with a light-proof lid, and some other work done until the alarm indicates that development is complete. When done in this way, development is reduced to a routine procedure which not only insures the best quality of properly exposed films, but also brings out all defects in exposure so that they may be corrected.

As a developing solution is used, there is a gradual decrease in the quantity of useful chemicals remaining in it. The amount of reduction in strength depends on the number of films that have been developed, and on the care that has been exercised to prevent deterioration and contamination of the solution. If exposed to the air, oxidation of the chemicals gradually takes place. This can be retarded by keeping the developer covered when not in use, and prevented by a float that rests on the top of the solution. A thin, dry board, of the proper size, that has been soaked in hot paraffin, makes a good float.

Fixing bath is the chief source of contamination of a developing solution. This may be allowed to drip into the developing compartment of the tank when examining films as soon as fixation is complete, or it may be carried in on developing hangers. A dark-room light used for viewing films after fixation should never be over the developing compartment of the tank. In washing films care should be exercised to remove all of the fixing bath from the cross-bars of the hangers. If this is not done, the solution will dry and be carried into the developer with the next films.

A reduction in the strength of the developer from exhaustion and contamination requires an increase in the time of development. A method of determining the requisite increase in time has been worked out by Wilsey and Norris, to which Schons has added a method of ascertaining time corrections for temperature variations between 65° and 70° F. This is considered so important that the method as given by Schons is included in detail.

Put a 5- by 7- or 6½- by 8½-inch film in a cardboard exposure holder, cover the middle portion lengthwise with a strip of lead 1½ to 2 inches in width and expose for 15 milliampere-seconds, using 85 peak kilovolts (5-inch spark gap), 28-inch anode-film distance, and a ½ or 1 millimeter aluminum filter. A record of the exact settings of the machine for this exposure should be kept so that it may be repeated at any time. In the dark room cut this film and its black paper cover lengthwise through the middle so as to have two pieces, each with an exposed and unexposed portion.

The test depends on the determination of the time of the appear-

ance of a line of demarcation between the exposed and unexposed portions of the film. To make the test, first take the temperature of the developing solution. Then remain in the dark room until the pupils of the eyes have dilated so that vision is acute. Partly fill a glass with developer and set it near the dark-room light. Cut two narrow strips from one piece of the exposed film and immerse one in the developer in the glass. Accurately determine the time in seconds required for the appearance of the line of demarcation. As a check, repeat with the other strip. The rest of the film should be preserved and protected for other tests.

The manner of determining the time of development for the different temperatures is given by Schons as follows:

"Using the chart (Fig. 34), find on the left side of the upper border the number of seconds at which the image appeared. Follow this line down to its intersection with the oblique line representing the temperature at which the test was made. This point of intersection when followed horizontally to the left side of the chart shows the approximate number of seconds at which the image would have appeared if the test had been made at 65° and represents the speed of the developer at the time of the test. The intersection of this horizontal line with the second group of oblique lines shows, when followed to the bottom of the chart, the correct time of development in minutes.

"For instance, at a temperature of 68° it takes thirty seconds for the image to appear. Following the thirty-second line down to its intersection with the 68° F. line, we find that when the horizontal line passing approximately through this point of intersection is followed to the left, it indicates thirty-four seconds. This shows that the developer is much weaker than freshly prepared developer, in which the image would appear at about twenty-five seconds at 65° F. The solution is, however, still very good and will produce excellent films provided development is carried to the proper point. Following this horizontal line to the right to the second group of oblique lines, and then following the points of intersection down to the bottom of the chart we find that the time of development must be approximately as follows for the different temperatures:

70° about five and one-half minutes.
69° about five and three-quarter minutes.
68° about six and one-quarter minutes.
67° about six and one-half minutes.
66° about six and three-quarter minutes.
65° about seven minutes.

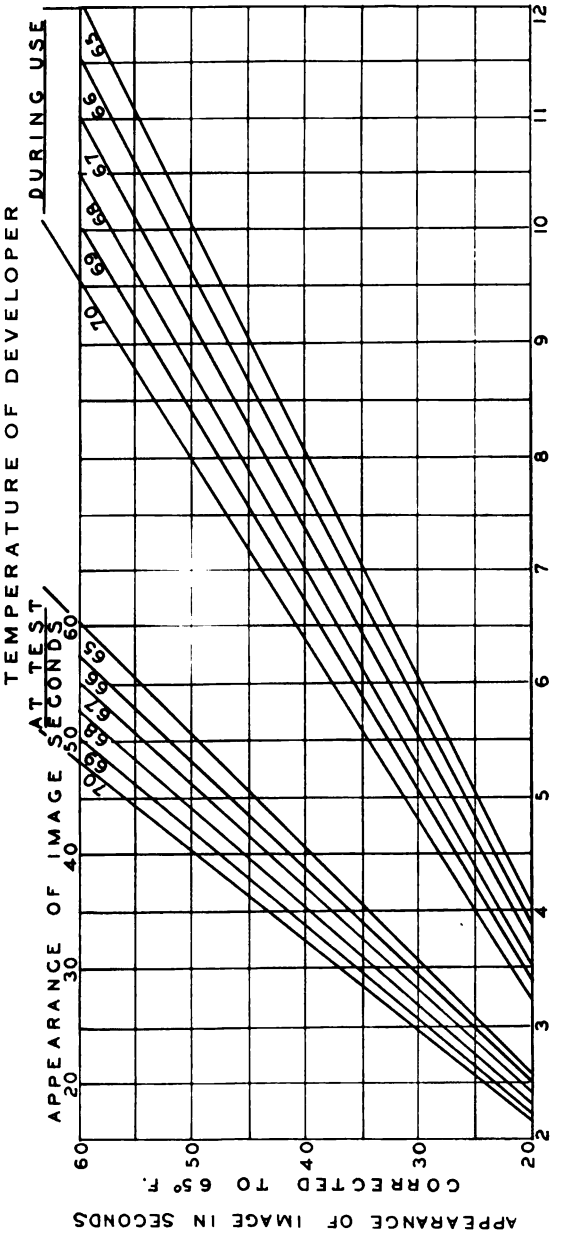
TEMPERATURE OF DEVELOPER DURING USE
APPEARANCE OF IMAGE SECONDS AT TEST
DEVELOPING TIME-MINUTES
APPEARANCE OF IMAGE IN SECONDS CORRECTED TO 65° F.

FIG. 34.—A chart for quickly ascertaining the proper time of development as developing solution becomes weakened from continued use, according to the method described by Schons. The method of using this chart is given in the text.

For convenience, enter these figures in one column on the tally chart (Table II) and develop according to this schedule until the next test is made."

		New		
Date of test		Sept. 9	Sept. 7	Sept. 11
Time of appearance of image in seconds		22	24	30
Temperature of developer at time test is made		68	70	68
Time of development in minutes. (From chart Fig. 34.)	70° F.	4	4¾	5½
	69° F.	4¼	5	5¾
	68° F.	4½	5¼	6¼
	67° F.	4½	5½	6½
	66° F.	4¾	5¾	6¾
	65° F.	5	6	7

TABLE II.—Daily tally chart for the development of films to be used with the chart in Fig. 34. (Schons.)

Defects in exposures of Roentgen-ray films cannot be corrected by shortening or lengthening the development. The images on an overexposed film will appear very quickly. If the development is shortened, both detail and contrast will be lacking; if carried out to the correct time, the film will be so black that except with the strongest illumination the images cannot be seen. Underexposure results in a flat film, without contrast, which no variation in development will correct. When doubt exists as to what constitutes a correct exposure, the universal practice seems to be to overexpose the films and to attempt to compensate for this by underdevelopment.

In the handling of Roentgen-ray films, when development is completed they should be taken from the solution and the excess liquid permitted to drip back into the tank. They should then be rinsed in water for five to ten seconds and transferred to the fixing bath. They should remain in the fixer for a time twice that required to dissolve out the unaffected silver from the emulsion or twice the time required for the films to become perfectly clear. Following fixation, they must be thoroughly washed to remove the chemicals of the fixing bath. This requires ten minutes in running water or twice as long in still water. The film is then ready to be hung up to dry.

The fixing bath and the rinsing and washing water must be as cool or cooler than the developer. A temperature of these solutions that is too high will cause frilling of the emulsion, or cause it to be washed off the base. If the washing compartment of a tank is large enough and it is necessary to either cool or warm the water, the temperature may be regulated once each day and all films for that day washed in it.

In concluding this chapter, emphasis is again placed on the importance of the correct development of Roentgen-ray films. Their immersion in the different solutions for the correct time, at the correct temperature, is the only way that this can be done. A correctly exposed film may be seriously impaired by improper development; no variation in development will compensate for an incorrect exposure.

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CHAPTER VI.

INTRODUCTORY EXPERIMENTS.

SKILL in roentgenographic technique requires a knowledge of the operating characteristics of Roentgen-ray machines, an understanding of the laws which govern Roentgen-ray exposures, the ability to select correct combinations of factors for exposing films of any part of the body, and dexterity in posing patients and placing films and tube so that the best roentgenograms will be obtained.

Skill of this kind requires training and experience. These probably can be acquired more quickly and thoroughly by instruction in a postgraduate school, a school of technique, or by a period of training under a competent roentgenologist. Skill may also be developed by working alone in a Roentgen-ray laboratory. With this in mind, to guide the beginner in learning Roentgen-ray technique and to be used in teaching, a number of experiments have been introduced in this chapter.

Experiments 1, 2, and 3 include the directions for making a working calibration of any Roentgen-ray machine producing rectified current, irrespective of its type. Since an essential part of the basis of Roentgen-ray technique is a knowledge of the operation of the machine, the information obtained from these experiments is of the greatest importance. The experiments include the preparation of tables and charts. The figures given in those used as illustrations were obtained by performing them as they are given and only apply to one particular Roentgen-ray machine. When performed on any other machine, peculiarities in construction and operating characteristics will give other results. These differences make it imperative that the tables and charts be prepared during the experiments.

Experiments 4, 5, and 6 are included to illustrate and explain the laws which govern roentgenographic exposures. A thorough knowledge of these laws is the second requisite for skill in technique. In Chapter VII is introduced the idea of establishing a basic roentgenographic technique, from which, by using these laws, the greater part of all technique may be derived. In order that the modifica-

tions of the basic technique be understood, it is essential that these laws be thoroughly comprehended. For this reason it is urged that these experiments be performed and a careful study made by the explanation which follows each experiment.

Experiment 1.

Object.—To study the voltages of the electric current in the low (primary) and high (secondary) voltage circuits of a Roentgen-ray machine, and, with a constant milliamperage, to determine control settings and voltmeter readings for different secondary voltage values.

This experiment can be performed with any Roentgen-ray machine of the interrupterless type having a motor-driven rectifier. It cannot be performed on one of the unit type nor on one having valve-tube or kenetron rectification of the secondary current. For the latter, the manufacturers must be depended on for the information obtained in Experiments 1 and 3. The directions are written for a machine having both autotransformer and rheostat control of the primary voltage. For machines equipped only with autotransformer control, the directions with reference to a rheostat may be disregarded. A broad or medium focus, or the 5–100 radiator type Coolidge tube, should be used in this experiment. If the tube capacity is not exceeded, it will not be damaged. It is best to proceed cautiously, and if the target of the universal tube becomes white hot, permit it to cool before continuing with the experiment. If it can be avoided, the rheostat should not be used. On many Roentgen-ray machines the autotransformer steps are so fine that all the voltages necessary for roentgenographic work can be obtained by the use of the autotransformer. On others the autotransformer steps are so coarse that the rheostat must be used for many of the intermediate voltages.

1. Close the supply-line and main switches and start the motor. If necessary, close the filament switch. Place the autotransformer control on the lowest button and the rheostat control on the button that takes it all out of the primary circuit. Close the Roentgen-ray switch and adjust the filament regulator so that exactly 20 milliamperes are passing through the tube. The milliamperage should be kept constant at 20 throughout the experiment.

2. Close the Roentgen-ray switch and slowly bring the terminals of the spark gap nearer each other until a spark jumps across

the gap, then open the Roentgen-ray switch. Note the position of the needle of the voltmeter in the primary circuit. If the spark gap is a point gap, measure the width of the gap; if a sphere gap, read the number of peak kilovolts from the scale. These will give the potential of the high-voltage current measured as spark gap in inches, or as peak kilovolts, and the voltmeter reading for the lowest autotransformer setting on the machine.

TABLE III.

Primary or low-voltage circuit.			Secondary or high-voltage circuit.			
C. S.		V. R.	S. G.	E. K. V.	P. K. V.	P. K. V.
A. T.	R.					
A–1	10	32.5	2.5	35	49	46
A–3	10	36.5	3.0	40	56	57
B–1	10	42.5	3.5	45	63	66
B–3	10	48.0	4.0	50	70	72
B–4	10	53.0	4.5	55	77	76
C–2	10	56.0	5.0	60	84	83
C–4	10	61.0	5.5	65	91	89
D–2	10	66.0	6.0	70	98	98

TABLE III.—An example of the table showing voltmeter readings and secondary voltage determinations to be prepared during the performance of Experiment 1. Note that the machine used has two autotransformer controls and a voltmeter calibrated in effective kilovolts. In columns 5 and 6 the values given the secondary voltages were determined from the spark-gap measurements by calculations. The peak kilovolts given in column 7 were measured with a sphere gap. A comparison of the calculated and measured peak kilovolts gives an idea of the accuracy of point-gap measurements on this machine at the time and place of these tests. CS, control settings; AT, autotransformer; R, rheostat; VR, voltmeter readings; SG, spark gap in inches; EKV, effective kilovolts; PKV, peak kilovolts.

3. Prepare a table similar to Table III and fill in as many of the columns as possible. These should include at least the control settings, the voltmeter readings, the determinations of the voltages of the secondary current either as spark gap in inches or as peak kilovolts, and calculations of the secondary voltages in terms of the other two voltage units as given on page 97.

4. Proceed in a like manner with a determination of the voltmeter readings and control settings for each of the spark-gap measurements shown in column 4, or the peak kilovolt values shown in column 6. If a point gap is used, these include spark-gap measurements in steps of $\frac{1}{2}$ inch, from 2 or $2\frac{1}{2}$ to 6 inches; if a sphere gap is used, they include voltage determinations in steps of 7 from 42 to 98 peak kilovolts. The most accurate determinations are made when the current is flowing through the tube and the terminals of the gap are approximated until the current arcs from terminal to terminal. Before the most accurate is found, it may be necessary to use more

than one control setting for each voltage value. Carefully record all observations in the table.

Discussion.—The potential of the current in the primary circuit of a Roentgen-ray machine is measured in volts and varies from about 60 to 200 volts. It is varied or changed by the autotransformer acting alone, or by the autotransformer and rheostat acting together, through which the current passes between the supply line and the primary coil of the Roentgen-ray transformer. The number of different primary voltages that are available for use depends on the construction of the autotransformer and rheostat. Since each primary voltage, with a particular milliamperage, will give a certain voltage in the secondary circuit of a Roentgen-ray machine, the number of secondary voltages also depends directly on the construction of the autotransformer and rheostat in the primary circuit.

Unfortunately the construction of the control devices in the primary circuits of Roentgen-ray machines has not been standardized, different manufacturers making differently constructed instruments. Interrupterless type machines made by two well-known manufacturers have autotransformers which begin at 60 or 80 volts and increase the primary voltage in steps of 5 volts. On these machines, using 20 milliamperes, increasing the primary current in 5-volt steps will increase the secondary voltage in steps of approximately $\frac{1}{4}$-inch spark gap ($2\frac{1}{2}$ effective or $3\frac{1}{2}$ peak kilovolts). Between 42 and 100 peak kilovolts (2- and 6-inch spark gap), which includes the range of secondary voltages useful in roentgenography, steps of this kind will give at least 17 useful secondary voltages, a number that has been found adequate for most roentgenographic work.

Autotransformers constructed to give primary steps of 5 volts or less may be used without a rheostat to control the primary voltage. If the autotransformer gives more than 5-volt steps and, therefore, larger intervals than $3\frac{1}{2}$ peak kilovolts ($\frac{1}{4}$-inch spark gap) in the secondary circuit, the rheostat may be used with the autotransformer to control the primary voltage. An advantage of autotransformer control over combined autotransformer and rheostat control is the fact that each autotransformer change is registered by a prereading voltmeter in the primary circuit, while the introduction of the rheostat produces no effect on the reading of the voltmeter except during actual exposures. This makes a decided difference in the operating characteristics of Roentgen-ray machines, and divides them into two classes. In the first class are those having a volt-

meter and an autotransformer that will give all the secondary voltages necessary for roentgenographic work. In the second class are those not equipped with a voltmeter and those with which it is necessary to use the rheostat to control the primary voltage.

In the first class the primary voltage is measured by a voltmeter in the primary circuit. These instruments are of three kinds: one with the scale reading in alternating current volts, one with the scale reading either in effective or peak kilovolts, and the third with the scale showing arbitrary divisions, usually from 1 to 100, and often called a potential indicator (Fig. 10). The last two are alternating current voltmeters similar to the first, differing only in the calibrations on the scale. When reading in kilovolts, the scale is intended as an indicator of effective or peak kilovolts which will be produced in the high-voltage circuit by that particular primary voltage.

With autotransformer control, a voltmeter measurement of the primary current is an accurate indicator of the secondary voltage. When it has once been determined that a certain voltmeter reading will give a particular kilovoltage with a known milliamperage, if the milliamperage remains unchanged, at any future time that kilovoltage can be secured by setting the primary controls to give the same voltmeter reading. This makes it possible to calibrate Roentgen-ray machines of this class by determining the voltmeter readings that will give different kilovoltages with different milliamperages, and to use afterward the voltmeter readings as indicators of the potential of the high-voltage current delivered to the Roentgen-ray tube.

In the second class may be placed all machines not equipped with a prereading voltmeter and those in which the rheostat must be used with the autotransformer to secure secondary voltage steps of $3\frac{1}{2}$ peak kilovolts ($\frac{1}{4}$-inch spark gap) or less. Without actual testing, on these machines the only indicators of secondary voltages are the control settings. Because of fluctuations in the supply-line current, these are not always accurate. When dependence must be placed on them, it frequently may be necessary to check the secondary voltage measurements by means of the spark gap.

The voltage in the high-voltage or secondary circuit of a Roentgen-ray machine is commonly measured by some form of spark gap. Of these there are three chief forms: one in which the gap terminals are needle points, one in which the terminals are sharp or moderately blunt points, and one in which the terminals are in the form of

spheres. Of these the needle-point gap (new sewing needles) and those having the terminals made of spheres of various sizes have been more or less standardized. The American Institute of Electrical Engineers recommends the use of needle points for voltages between 15 and 70 peak kilovolts and the use of spheres of various sizes for voltages varying between 15 and 550 peak kilovolts, one with spheres $62\frac{1}{2}$ millimeters in diameter being suitable for voltages between 15 and 120 peak kilovolts, which includes the range useful in roentgenography. A needle-point gap is not especially suitable, for a pair of needles are only usable four or five times before the points become worn and the gap no longer accurate.

The use of a point spark gap (sharp or moderately blunt points) for the measurement of high potential electric currents probably is limited to the manufacturers and users of Roentgen-ray apparatus, no other profession using such an instrument for this purpose. Practically all Roentgen-ray machines of older manufacture and many of those now being delivered are equipped with such instruments by means of which measurements of voltage in inches of gap may be made. Measurements made by them are admittedly somewhat inaccurate, yet the prevalence of this form of equipment and the sanction of years of usage compels a consideration of this form of voltage measurement.

The inaccuracies of point-gap measurements are due to several causes. One of the chief of these is a lack of standardization in the construction of the gap, each manufacturer adopting and following his own method of construction. The standard established by one manufacturer, for example, is the use of $\frac{3}{16}$-inch brass rods which are tapered to points to be dulled using a $\frac{1}{32}$-inch radius when rounding off the points. A gap of this sort may change its characteristics from the undue heat at the point tips gradually burning off the metal and changing the size and shape of the gap terminals.

Point-gap measurements are also influenced by the character of the potential, the density of the air, the humidity, the temperature, and other factors. Of these the most important is air density caused chiefly by differences in altitude. Markley found that a potential that would give a 6-inch gap at sea level would give an 8.7-inch gap at an altitude of 7500 feet, due to the lessened density of the air; that 100 peak kilovolts would give a 6-inch gap at sea level but that at 7500 feet elevation only 78.7 peak kilovolts are required for a 6-inch gap between points. He found that the effect of humidity is considerably less, the greater the humidity the shorter the gap for a given peak kilovoltage.

Temperature, humidity, and air density also influence sphere-gap measurements, but when corrections are made for the differences in air density due to altitude, the other factors may be disregarded.

From this discussion of the measurements of voltages in the secondary circuit of a Roentgen-ray machine, it is apparent that the most accurate are those made with a suitable sphere gap which has been corrected for altitude. For this reason Experiments 1 and 3 should, whenever possible, be performed with a sphere gap. If a sphere gap is not available, however, or if one cannot be obtained for performing the calibrations given in these two experiments, then they should be performed with whatever form of spark gap the equipment includes. If the variations in point-gap readings, especially with reference to altitude, are remembered and the determinations of voltage as spark gap in inches are used in conjunction with a method of measuring the Roentgen-ray output of a given Roentgen-ray machine to be introduced later, point-gap calibrations may be made the basis for a very satisfactory roentgenographic technique.

At the present time, peak kilovoltage, determined by means of a sphere gap, is gradually superseding point-gap determinations in roentgenology. The former has displaced the latter almost completely in Roentgen therapy, but point-gap determinations are still used quite extensively in roentgenography. This makes it necessary to include, in all references to secondary voltages, the approximate values both in spark gap in inches and in peak kilovolts. In an attempt to determine as nearly as possible these values it was found that there was no standard of published data that could be accepted as authority. Tables collected from different sources give rather widely divergent comparative values. For example the value in peak kilovolts for a 3-inch spark gap varies from 55.5 to 63 peak kilovolts, and that for a 5-inch spark gap from 77.8 to 88 peak kilovolts. Because of these discrepancies, it has been necessary to arbitrarily select comparative values that are about midway between the extremes given above. These values were arrived at in the following way:

Shearer gives a chart showing the approximate relation between effective kilovolts and spark gap for moderately blunt points in which a 2-inch gap is equal to 30 kilovolts and each additional inch of gap up to 6½ inches adds 10 kilovolts. This would make a 5-inch gap equal 60 kilovolts, etc. Effective kilovolts may be changed to a value in peak kilovolts by multiplying by 1.41. Thus a 5-inch

spark gap or 60 effective kilovolts would be equal to 84.6 peak kilovolts, a ¼-inch spark gap to 3½, a ½-inch spark gap to 7 peak kilovolts, etc. In all references to secondary voltages this method of selecting the comparative values has been used. The value as given in peak kilovoltage is always accurate and based on sphere-gap determinations; that of the comparative value as spark gap in inches is only approximate.

In Experiment 1, considerable emphasis has been placed on voltage determinations. While the voltage measurements have been made in steps of 7 peak kilovolts or ½-inch spark gap, usually the controls of a Roentgen-ray machine are so constructed that steps of approximately ¼-inch or 3½ peak kilovolts can be obtained. When this is true, 17 or more different secondary voltages are available for use. Since the quality of the Roentgen-rays depends on the voltage of the current which produces them, with each milliamperage, as many variations in quality are available as there are available voltages.

EXPERIMENT 2.

Object.—To study the amperage of the current in the filament circuit and the milliamperage of the current in the high-voltage circuit of a Roentgen-ray machine.

This experiment need not be performed on an equipment that includes a Kearsley stabilizer in good working condition. This apparatus will give any desired milliamperage at any voltage and is a very useful instrument. It should be performed with all equipments that do not include a stabilizer and on those that include a stabilizer in the primary of the filament circuit. Prepare a table similar to the one in Table IV.

TABLE IV.

Spark gap.	Filament amperes. Milliamperes.				Filament scale. Milliamperes.			
	10.	20.	30.	40.	10.	20.	30.	40.
2 . .	3.90	4.15	4.25	4.35	6.25	6.8	7.40	7.7
3 . .	3.85	4.05	4.25	4.30	6.20	6.8	7.40	7.7
4 . .	3.85	4.00	4.20	4.25	6.20	6.7	7.30	7.6
5 . .	3.80	4.00	4.15	4.25	6.15	6.7	7.25	7.6
6 . .	3.80	3.90	4.12	4.22	6.10	6.6	7.10	7.5

TABLE IV.—An example of a table showing filament amperes and filament scale readings for different milliamperage and voltage values obtained during the performance of Experiment 2.

1. Start the machine and adjust the controls to the setting or voltmeter reading that will give a voltage equivalent to a 2-inch

spark gap, or 42 peak kilovolts, through the tube as determined in Experiment 1. Close the Roentgen-ray switch and adjust the filament regulator so that the milliamperemeter reads 10. Read the number of amperes in the filament circuit from the amperemeter and the position of the filament regulator as shown on the filament scale. Enter these readings in the table. Should either the meter or scale be omitted from the equipment, then only the other can be read and recorded.

2. With the same control setting and voltmeter reading, in a like manner proceed with the determination of the number of amperes in the filament circuit and the readings of the filament scale for the higher milliamperages, in steps of 10, permitted by the capacity of the tube being used.

3. Using the control settings and voltmeter readings determined in Experiment 1 for a 3, 4, 5, and 6-inch spark gap, or the equivalent peak kilovoltage, proceed to make similar filament amperage determinations and scale readings for the different milliamperages permitted by the tube. Carefully record all observations in the table.

Discussion.—The current through the filament of a Coolidge tube is of 12 volts, varying from 3 to 5 amperes. From the supply line, the voltage is reduced by the filament transformer, and the amperage is controlled by the filament regulator. The current through the filament heats it, causing it to give off electrons. These carry the high-voltage current from the cathode to the anode of the tube. The heat of the filament, the quantity of electrons, and the number of milliamperes of high-voltage current all depend on the filament current as measured in amperes. With a particular tube, operating at a certain voltage, a given amperage through the filament circuit will always give approximately the same milliamperage through the tube.

A careful study of the table prepared in this experiment will show that the milliamperes increase with an increase in the amperes of filament current and that the amount of filament current necessary to give a certain milliamperage varies slightly, usually dropping, as the voltage through the tube is increased. On machines that do not have an amperemeter in the filament circuit, readings of the filament current in amperes cannot be made. Dependence must then be placed on the readings of the scale on the filament regulator. This scale is usually purely arbitrary and means nothing except that it enables an operator to repeat a certain setting.

Because of line fluctuations, neither a particular filament amperage nor a scale reading is absolutely accurate. Adjustment to the exact milliamperage often must be made during a Roentgen-ray exposure. Because gross current fluctuations may be corrected by an amperemeter reading, this is more accurate than a scale setting in giving a desired milliamperage through a Roentgen-ray tube. Fluctuations in milliamperage may be prevented by the use of a stabilizer.

There is a difference in the resistance of the filament in different Coolidge tubes. Therefore different filament amperages may be required for a particular milliamperage in different tubes. If more than one tube is used for radiographic work, or if a tube is replaced, Experiment 2 should be performed for each tube.

The tables prepared in this experiment, one for each tube used, should be neatly copied and preserved for reference. If they are fastened to the wall near the control stand, they may be referred to at any time. From them may be obtained the filament amperage or scale reading for any milliamperage. Their use will make it unnecessary to do much testing of the milliamperes through the tube before exposures are made, thus prolonging the life of the tube.

EXPERIMENT 3.

Object.—To study the changes in the voltage of the electric current in the high-voltage circuit of a Roentgen-ray machine that are caused by changes in the milliamperage, and to determine the control settings and voltmeter readings that will give different voltages with different milliamperages.

This experiment cannot be performed with a unit type machine nor with one having valve-tube rectification of the secondary current. Since the results of this experiment may be used with any Coolidge tube, a medium or broad focus tube or the 5–100 radiator type tube should be used. If a medium focus tube is used, do not exceed 40 milliamperes; if a broad focus tube is used, the study may include 50 and 60 milliamperes, and even 80 milliamperes at the lower voltages. With either of these tubes, because of heating of the anode, it probably will be necessary to make the voltage determinations for one voltmeter reading at the various milliamperages, and then allow the tube to cool before proceeding with the next. If the 5–100 radiator tube is available, the study may be carried to 100 milliamperes with a voltage as high as a 5-inch spark gap (85 peak

kilovolts). Even with this tube the determinations should be made slowly to prevent damaging the tube from overheating.

TABLE V.

A. T.	R.	V. R.	S. G.	Milliamperes.					
				10.	20.	30.	40.	50.	60.
A–1	10	32.5	2.5	2.75	2.5	2.25	2.00		
A–3	10	37.5	3.0	3.25	3.0	2.75	2.45	2.0	2.0
B–1	10	42.5	3.5	3.75	3.5	3.25	3.00	2.8	2.6
B–3	10	48.0	4.0	4.25	4.0	3.80	3.50	3.2	3.0
B–4	10	53.0	4.5	4.75	4.5	4.25	4.00	3.8	3.6
C–2	10	56.0	5.0	5.20	5.0	4.75	4.50	4.3	4.1
C–4	10	61.0	5.5	5.70	5.5	5.30	5.10	4.8	4.6
D–2	10	66.0	6.0	6.20	6.0	5.80	5.60	5.4	5.2

TABLE V.—An example of the table showing different voltage values for various voltmeter readings with different milliamperages prepared during the performance of Experiment 3. The table is based on spark-gap measurements. Peak kilovolt determinations with a sphere gap are preferable. AT, autotransformer controls; R, rheostat control; VR, voltmeter readings; SG, spark gap in inches from Experiment 1.

1. Prepare a table similar to Table V and enter in the first four columns the control settings, voltmeter readings, and the voltage measurements determined in Experiment 1, and shown in the table similar to Table III prepared during the performance of that experiment.

2. Start the machine and adjust the controls so that the setting or voltmeter reading will give a 2½-inch spark gap or 49 peak kilovolts. Determine the milliamperes through the tube and adjust the filament regulator so that exactly 10 milliamperes are flowing. Then make a determination of the voltage in the secondary circuit as in Experiment 1. It will be found that it is more than 2½ inches or 49 peak kilovolts. This should be measured and the result entered in column 5 in the table.

3. Increase the milliamperes to 20 and determine the secondary voltage with the spark gap. This should be the same as previously determined in Experiment 1.

4. With the same settings, make determinations of the secondary voltage with 30 and 40 milliamperes, and if the tube permits, with higher milliamperages.

5. Proceed with each of the other control settings and voltmeter readings shown in column 1, 2, and 3 in the table and make voltage determination with 10, 20, 30, 40 and, if possible, with 50 and 60, and higher milliamperages. Enter all measurements in the table.

Discussion.—In Experiment 1, readings of the voltmeter and the control settings in the primary circuit of a Roentgen-ray machine for voltages in the secondary or high-voltage circuit equivalent to

spark-gap lengths from 2 or 2½ to 6 inches (42 to 98 peak kilovolts) were determined. In that experiment the milliamperage was kept constant at 20. In the discussion it was stated that, with the milliamperage constant, voltmeter readings, once determined, are an accurate indicator of voltages in the secondary circuit, and that control settings may also be used as secondary voltage indicators.

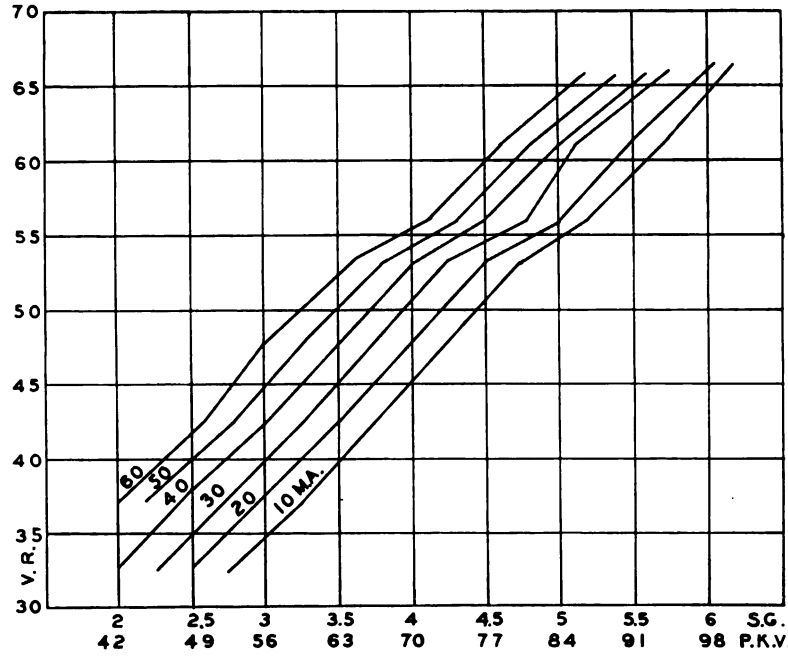

FIG. 35.—A chart made from the results of Experiment 3 as shown in Table V. From it may be obtained a voltmeter reading giving a particular voltage value with any of the milliamperages used in the experiment. The abscissæ are voltage values given both as spark gap in inches, SG, and as peak kilovolts, PKV; the ordinates are voltmeter scale readings, VR.

Experiment 3 shows the changes that are produced in the voltage in the high-voltage circuit caused by changes in the milliamperages. Beginning with certain voltage and milliamperage values, using a smaller number of milliamperes will increase the voltage; using a larger number of milliamperes will decrease the voltage in the secondary circuit.

For machines equipped with a voltmeter and using autotransformer control, from Table V a chart like Fig. 35 may be made. The ordinates of this chart are the voltmeter values used in Experi-

ments 1 and 3. The abscissæ show voltage as expressed in spark gap in inches, and as peak kilovolts. On the chart there is a line for each milliamperage used in Experiment 3. These lines are made by placing a dot at the crossing of the ordinate for each voltmeter setting with the abscissa from each voltage determination with each milliamperage. Connecting the dots for each milliamperage gives the lines on the chart.

This chart graphically shows the voltage changes caused by changes in milliamperage. A study of it shows that, with the particular machine used in obtaining the illustrative figures for the experiment, changing the milliamperes from 10 to 60 with each control setting and voltmeter reading, causes a voltage drop of 14 to 17 peak kilovolts, or an inch or more of spark gap, and that changing the milliamperes from 20 to 40 causes a voltage drop of approximately 7 peak kilovolts or ½-inch spark gap. These changes are slightly greater at the lower than at the higher initial voltages.

From this chart may also be obtained voltmeter settings for any voltage value between a 2- and 6-inch spark gap (42 and 98 peak kilovolts) with any milliamperage used in the experiment. When used for this purpose, following the ordinate for a certain voltage value from the bottom of the chart until it crosses the lines for the different milliamperages will give the proper voltmeter readings. These may be made into the table shown in Table VI. While the chart and the table give the same information, for quick reference the table is preferable.

TABLE VI.

Voltage values.		Milliamperes.					
S. G.	P. K. V.	10.	20.	30.	40.	50.	60.
2.00	42.0	..	..	30.0	32.5	35.5	37.5
2.25	45.5	..	30.0	32.5	35.0	38.0	40.0
2.50	49.0	30.0	32.5	35.0	37.5	40.0	42.0
2.75	52.5	32.5	35.0	37.5	40.0	42.0	45.0
3.00	56.0	35.0	37.5	40.0	42.5	45.0	47.5
3.25	59.5	37.5	40.0	42.5	45.0	47.5	50.0
3.50	63.0	40.0	42.5	45.0	47.5	50.0	52.5
3.75	66.5	42.5	45.0	47.5	50.0	52.5	54.0
4.00	70.0	45.0	47.5	50.0	53.0	54.0	55.0
4.25	73.5	47.5	51.0	53.0	54.0	56.0	57.5
4.50	77.0	50.0	53.0	55.0	56.0	57.5	60.0
4.75	80.5	53.0	55.0	56.0	59.0	61.0	62.5
5.00	84.0	55.0	56.0	59.0	61.0	62.5	64.0
5.25	87.5	56.0	58.0	62.0	63.0	65.0	
5.50	91.0	59.0	61.0	64.0	65.0		
5.75	94.5	62.0	64.0				
6.00	98.0	64.0	66.0				

TABLE VI.—A table prepared from the chart in Fig. 35 from which may be obtained the correct voltmeter readings for different secondary voltages with different milliamperages. Voltages in steps of ¼-inch spark gap and the equivalent in peak kilovolts are given. In many instances in actual work, the exact voltmeter reading cannot be obtained but it can be closely approximated.

When this experiment is performed on machines using combined autotransformer and rheostat control and on machines without a voltmeter, voltage determinations in steps of $\frac{1}{4}$-inch spark gap or $3\frac{1}{2}$ peak kilovolts or less with the various milliamperages should be made The control settings giving the different voltages with the different milliamperages should be carefully entered in the table prepared during the performance of the experiment. A table of this kind is shown in Table VII. Since it is impossible to make a chart or a table like those shown in Fig. 35 and Table VI with these machines, to obtain any secondary voltage with any milliamperage, reliance must be placed on the control settings as indicators of secondary voltages.

TABLE VII.

A. T.	R.	V. R.	Milliamperes.			
			10.	20.	30.	40.
1	15	9.0	61	50	42	32
1	14	..	59	46		
1	13	..	57	42		
2	15	11.5	68	62	52	44
2	14	..	67	57	50	40
2	13	..	64	53	43	35
2	12	..	57	40	30	
3	15	14.0	76	70	63	54
3	14	..	74	67	60	47
3	13	..	71	64	54	42
3	12	..	65	50	39	
4	15	17.0	82	78	72	64
4	14	..	80	76	69	60
4	13	..	78	72	63	55
4	12	..	70	60	50	39
5	15	19.5	88	86	82	73
5	14	..	86	84	78	71
5	13	..	83	80	73	65
5	12	..	80	72	57	47
6	15	23.0	96	94	88	80
6	14	..	93	92	86	77
6	13	..	87	86	83	73
6	12	..	79	76	66	55
7	15	26.5	104	100		
7	14	..	98	96		
7	13	..	96	94		

TABLE VII.—An example of a table prepared during the performance of Experiment 3 with a machine on which the rheostat was used with the autotransformer and on which the voltmeter is not sensitive enough to be of much use. The table shows sphere-gap measurements in peak kilovolts. With a machine of this kind control settings must be used as indicators of secondary voltage values. Since there is no way of detecting or compensating for fluctuations in the supply-line voltage, this method of determining secondary voltage is not always reliable. AT, autotransformer; R, rheostat; VR, voltmeter readings.

Voltage changes such as these are common to all Roentgen-ray machines, but in different machines there is considerable variation in the amount of voltage change. Using only autotransformer control, one machine that has been carefully tested does not give more than 13 peak kilovolts drop in increasing the milliamperage from 10 to 100. The same increase in milliamperage on a similar machine causes a voltage drop of 28 peak kilovolts or 2 inches, as measured by a point spark gap.

It is impossible to perform Experiments 1 and 3 with a machine having valve-tube rectification in the secondary circuit. In these machines and in the unit type the suppressed half of the high-voltage current has a higher voltage than that which passes through the tube and the use of a spark gap is apt to puncture the rectifying or Roentgen-ray tube. The information that may be obtained from these experiments is provided by the manufacturers either in the form of a chart showing voltmeter readings for different voltages with various milliamperages, or in the form of a specially calibrated voltmeter. One concern making valve-tube apparatus has added a small milliampere scale at the left or zero side of the voltmeter. By placing the indicator hand of the voltmeter on the setting for the milliamperage that is to be used before the main switch is closed, during the exposure the voltmeter will read in terms of peak kilovolts with that milliamperage in the secondary circuit. This is an ingenious device that, if accurate, should answer the purpose of the calibrations given in these experiments.

Since the quality or penetrability of Roentgen-rays depends on the voltage with which they are produced, it is essential that the voltage used in every roentgenographic exposure be known as nearly as possible. Relatively slight errors in voltage will give marked errors in the exposure of films. These are such that the selection of the proper voltage is probably the most important factor in roentgenography.

Many different combinations of voltage and milliamperage may be used in exposing films of different parts of the body. While milliamperages may be read at any time from the meter, voltages must be determined by the control settings and voltmeter readings before exposures begin. Therefore, the voltage determinations in Experiment 3 are of the greatest importance, and, to avoid future errors, should be made as accurately as possible.

EXPERIMENT 4.[1]

Object.—To demonstrate the laws that, if the other factors remain constant, the intensity of a Roentgen-ray exposure as measured by its photographic effect, varies directly as the milliamperes through the tube, and directly as the time of the exposure.

1. Mark off with a pencil ten areas of equal size on a 6½- by 8½-inch film exposure holder, five on each side of a line dividing it lengthwise into two equal parts. Beginning at the upper left-hand corner and extending downward, number the areas on the left half from 1 to 5 and those on the right half from 6 to 10. Put a film with its black paper cover in the holder.

2. Put a small cone in the tube stand, start the machine, adjust the voltage so that the equivalent of a 3-inch spark gap, or 56 peak kilovolts, is passing through the tube. Adjust the milliamperes so that 5 are flowing. Adjust the tube so that the anode-film distance is 30 inches. Place a lead figure "4" on area 1, cover all the remainder of the film holder with sheet lead or lead rubber, and expose the first area for six seconds.

3. Using the same voltage and anode-film distance, continue exposing the areas one at a time, using the milliamperes and time given in the following table. In testing the milliamperage, be certain that all of the film is covered with lead.

TABLE VIII.

Area No.	Ma.	Time in seconds.
1	5	6.0
2	10	3.0
3	15	2.0
4	20	1.5
5	30	1.0
6	5	2.0
7	10	2.0
8	15	2.0
9	20	2.0
10	25	2.0

4. When the exposures have been completed, develop the film until the lightest area, No. 6, shows some blackening, disregarding the density of the other areas (Fig. 36). Fix, wash, and dry the film.

[1] The idea of demonstrating the laws of roentgenographic exposures by means of experiments, particularly Experiments 4, 5, and 6, was obtained from the United States Army *X*-ray Manual.

Discussion.—The finished film will show that areas 1 to 5 are of nearly the same density or degree of blackening, or that essentially the same amount of the silver in the emulsion has been affected by the Roentgen-rays. Areas 6 to 10 will show a progressive increase in the density of the different areas. In the exposure of areas 1 to 5, the milliamperes through the tube have been increased from 5 to 30, but the time has been correspondingly decreased. For each of these areas, a quantity of Roentgen-rays equal to 30 milliampere-seconds has been used. In increasing the milliamperes from 5 to

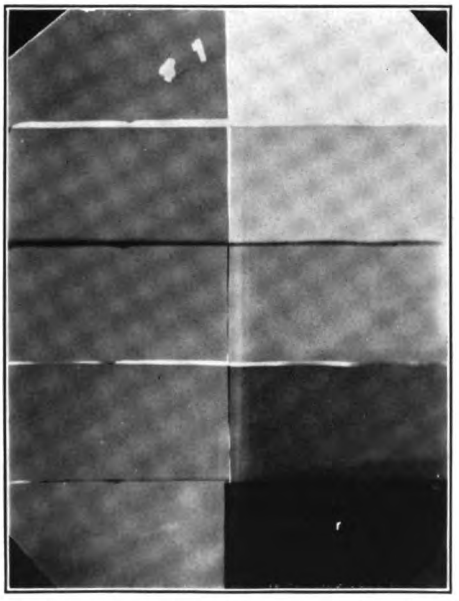

FIG. 36.—A photographic reproduction of a film exposed during the performance of Experiment 4. Those from Experiments 5 and 6 are similar.

30, there has been some decrease in the voltage through the tube, but this will not materially change the results. For the last five areas, the quantity of Roentgen-rays has been increased from that represented by 10 milliampere-seconds to that of 50 milliampere-seconds. This graded increase in quantity should cause a definite and regular increase in the density or blackening of these areas. The density of area 7 should be twice that of area 6; that of area 8, three times; of 9, four times, and that of area 10, five times that of area 6.

This experiment should show, therefore, that with voltage and distance constant, the photographic effect of Roentgen-ray exposures varies directly as the number of milliampere-seconds used. If the milliamperes are kept constant, it varies directly as the variations in the time of the exposure; if the time is kept constant, the photographic effect varies directly as the variations in milliamperes. Thus if an exposure is made with any milliamperage for a certain number of seconds, doubling the time will double the photographic effect; halving the time will reduce the effect to one-half. Or if an exposure is made with a particular milliamperage for a certain time, increasing or decreasing the milliamperes will correspondingly increase or decrease the photographic effect.

In calculating such variations in photographic effect, it is convenient to multiply the milliamperes by the time in seconds and use milliampere-seconds, thus using one number instead of two.

Experiment 5.

Object.—To demonstrate the effect of a change in anode-film distance, and prove the law that, other factors remaining constant, the intensity of a Roentgen-ray exposure varies inversely as the square of the anode-film distance.

Place a film in an exposure holder as in Experiment 4. Use 10 milliamperes and a voltage equivalent to a 3-inch spark gap or 56 peak kilovolts. Expose the different areas with the distances and times given in the following table. For the shortest distance, the cone must be removed from the tube stand; for the longest, the film must be put on a chair or on the floor. Measure all distances with a tape measure. Be certain that the film is numbered to correspond to the number of the experiment.

Table IX.

Area No.	Distance in inches.	Time in seconds.
1	10	0.5
2	20	2.0
3	30	4.5
4	40	8.0
5	50	12.5
6	10	1.0
7	20	1.0
8	30	1.0
9	40	1.0
10	50	1.0

Develop the film until the lightest area, No. 10, shows some blackening. Fix, wash, and dry it.

Discussion.—On this film, areas 1 to 5 will have approximately the same density, while areas 6 to 10 will decrease in density from the first to the last. In both series of five exposures the distance was increased from 10 to 50 inches. In the first series the increases in distance were compensated for by increases in the time of the exposure. In the second series the time of the exposures remained constant.

Roentgen-rays originate at the focal spot of the anode of a Roentgen-ray tube, spread out in all directions in a hemisphere of which the focal spot is the center, and travel until they are intercepted by some object or substance in their path. At a certain distance from the tube anode, a given area of surface will intercept a certain quantity of the rays. If this same area is moved either nearer or farther from the tube, the quantity of rays striking it will have a definite relationship to the distance it has been moved.

For example, in the experiment, area 1, at 10 inches from the anode, received a certain quantity of rays that produced a blackening of the film when it was developed. Moving the tube for area 2 so as to increase the distance to 20 inches caused the rays to spread out so that at 20 inches they cover an area four times as large. With the same time of exposure, area 2 would receive only one-fourth as much radiation as area 1. To keep the radiation constant, as measured photographically, the exposure of area 2 was increased to four times that of area 1.

Area 1 was exposed at a distance of 10 inches, the square of which is 100; area 2 was exposed at a distance of 20 inches, the square of which is 400. These are to each other as 100 is to 400 or as 1 is to 4. The exposures of areas 3, 4, and 5, compared with that on area 1, were at the ratios of 9, 16, and 25, which are the same as the squares of the distances used. It may be said, therefore, that the relationship of exposure times of two areas, other factors remaining constant, varies as the square of the anode-film distances.

In exposing areas 6 to 10 the time remained constant, but the distances were increased. Area 7 received one-fourth as much radiation intensity as area 6. The squares of the distances are 100 and 400. Inverting these two numbers, area 6 received an intensity of 400 compared to 100 for area 7, or a ratio of 4 to 1. Therefore, with the other exposure factors constant, the intensity of Roentgen-ray exposures varies inversely as the squares of the anode-film distances.

This law is one of the most important and most useful in roentgenography. If the factors that will give a satisfactory film at one distance are known, and it is wished to expose a film at a different distance, the voltage and milliamperage can be kept constant and the time of the exposure at the new distance calculated from the following formula: $T:T'::D:D'$, where T is the known time, T′ the unknown time, D the known distance, and D′ the desired distance.

For example, if five seconds were appropriate for a 35-inch distance, the time for 25 inches would be determined as follows:

$$5 : T' :: 35^2 : 25^2$$

or $5 : T' :: 1225 : 625$

or $1225\,T = 3125$

or $T' = \frac{3125}{1225}$ or $T' = 2.5$ seconds, the appropriate time for 25 inches.

Inasmuch as the intensity of an exposure varies directly as the milliamperes used, if the milliamperes at one distance are known, using the same time, a proper milliamperage for any other distance may be calculated in a similar manner. It is perhaps preferable to combine the milliamperes and time to form milliampere-seconds and make the calculation using milliampere-seconds. When once determined, any combination of milliamperes and time may be used just so that they give the appropriate milliampere-seconds.

For example, if 100 is the proper number of milliampere-seconds at 35 inches in distance, and the number at 25 inches is sought, the calculation would be as follows:

$$100 : MAS' :: 35^2 : 25^2$$

or $100 : MAS' :: 1225 : 625$

or $1225\,MAS' = 62500$

or $MAS' = \frac{62500}{1225}$ or $MAS' = 51.$

An exposure using 51 milliampere-seconds at a 25-inch distance would give the same radiation intensity as 100 milliampere-seconds at 35 inches. The latter may have been produced by 20 milliamperes for five seconds; the 51 may be closely approximated by 25 milliamperes for two seconds.

Based on this law, charts, showing changes in either time, milliamperes, or milliampere-seconds necessary to compensate for changes

in distance, may be prepared and used for reference. Such charts are shown in Figs. 37 and 38. From them may be obtained a factor to be used in calculating a new value in either time, milliamperes, or milliampere-seconds, at any distance from 15 to 35 inches, when the

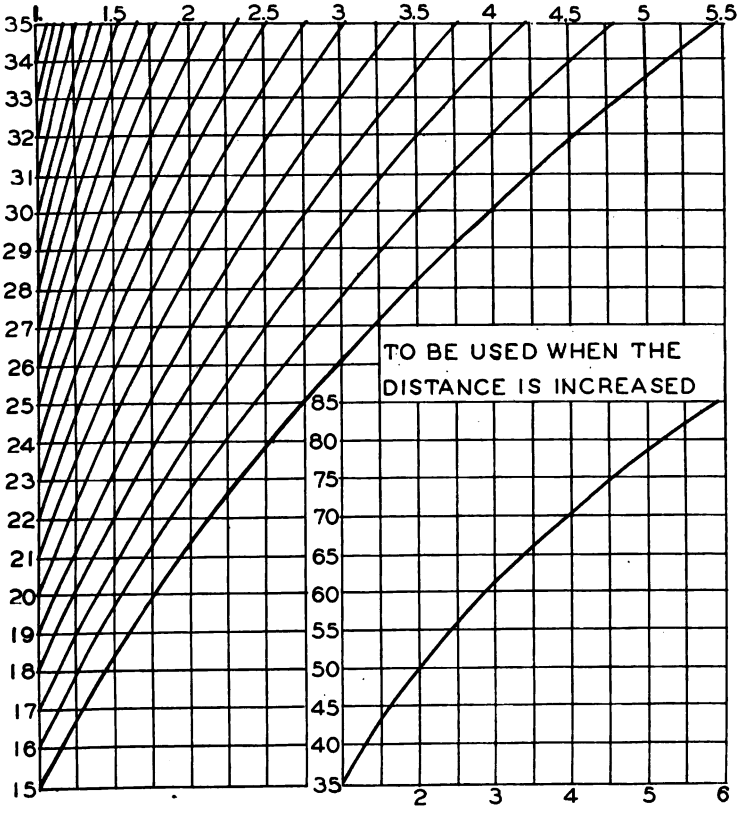

FIG. 37.—A chart, based on the inverse-square law, from which may be obtained a factor for multiplying the time, milliamperes or the milliampere-seconds of a known Roentgen-ray exposure when the distance is to be increased. The larger section of the chart shows all distances between 15 and 35 inches. The factor is obtained from the abscissæ on the top of the chart. The smaller section is based on a known exposure at a 35-inch distance and gives the factors necessary for increases in distance up to 85 inches. The factors are the abscissæ on the bottom of the chart.

value of these at any other distance is known. They may also be used for determining a new distance appropriate for any desired number of milliampere-seconds.

In these charts the distances are given as the ordinates; the abscissæ are the factors. In both charts the known factors are

represented by the abscissa 1. Fig. 37 is to be used when the distance is to be increased and Fig. 38 when it is to be decreased. The following examples explain the method of using these charts.

If the milliamperes and time are known for a proper exposure at 15 inches, and an exposure at a greater distance is desired, begin

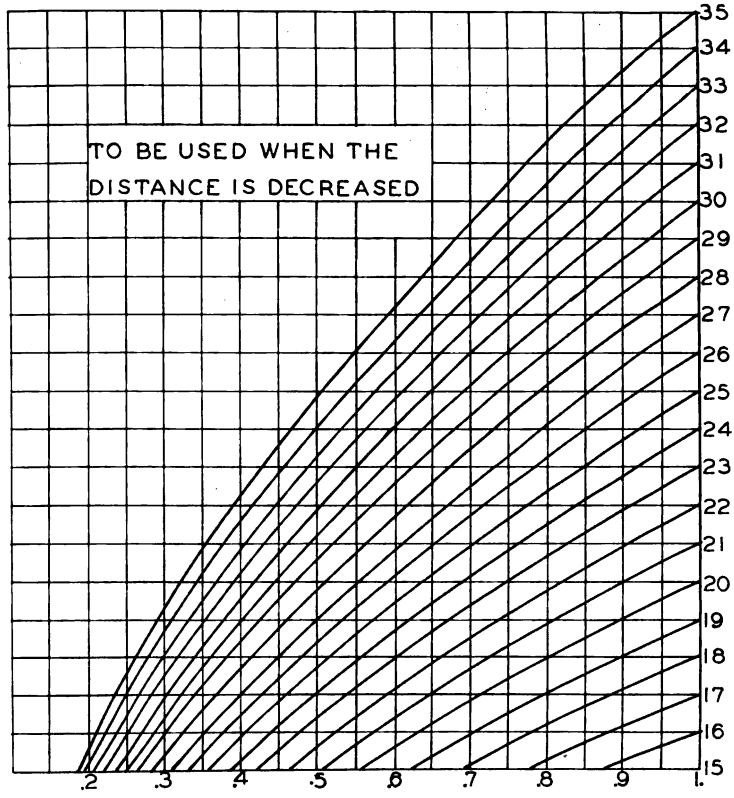

FIG. 38.—A chart from which may be obtained a factor for multiplying the time, milliamperes, or milliampere-seconds of a known Roentgen-ray exposure to obtain the correct value when the distance is to be decreased. The factors are the abscissæ, on the bottom of the chart.

at 15 on the line 1, Fig. 37, and follow the line of the chart upward and to the right until it crosses the ordinate for the desired distance, obtaining the number to be used as a multiplier from the abscissæ. At 20, 25, 30, and 35 inches, the milliampere-seconds would need to be multiplied by 1.7, 2.7, 4, and 5.5 respectively. Again if the factors are known for an exposure at 25 inches and 35 inches is a

preferable distance, begin at 25 on the line 1 and follow it to the ordinate for 35, the proper number obtained from the abscissæ is approximately 2. Multiplying the milliampere-seconds for the former distance by 2 will give the correct number for an exposure at 35 inches.

Fig. 38 is to be used when the distance is to be decreased. Readings are made in much the same manner as for the other chart, except that the start is made at the line 1 on the right side of the figure, the lines of the chart being followed downward and toward the left. For example, if the correct factors are known for a 35-inch distance, following this line of the chart will give approximately 0.75 at 30 inches, 0.5 at 25 inches, and 0.32 at 20 inches. Multiplying the milliampere-seconds known to give a good exposure at 35 inches by either of these factors will give the correct number of milliampere-seconds at the new distance.

Again, if the exposure factors include 100 milliampere-seconds at 35 inches and for any reason it is preferable to make an exposure in one second using 40 milliamperes, beginning at 35 on the line 1 and following the line of the chart, the line will cross the abscissa 0.4 at the ordinate for 22 inches ($100 \times 0.4 = 40$). This shows that the same intensity of exposure will be obtained with 40 milliampere-seconds at 22 inches as with 100 milliampere-seconds at 35 inches.

In roentgenological work all distances should be accurately measured. In addition to the scale on the tube stand, if a tape measure is fastened to the tube stand, with one end at the level of the tube anode, distance measurements may easily be made. Since errors in distance may cause considerable variations in the density of the films, an accurate distance measurement should be a routine part of each roentgenographic exposure.

EXPERIMENT 6.

Object.—To study the effect of voltage on Roentgen-ray exposures, and to prove the law that, other factors remaining constant, the intensity of a Roentgen-ray exposure, measured photographically, varies as the square of the voltage.

Use a film in an exposure holder as in the preceding experiment. Keep the milliamperes constant at 10 and the distance at 35 inches. Expose the different areas, using the voltages and times given in the following table. Obtain the proper voltmeter settings from the chart prepared in Experiment 3. Be certain to number the film.

TABLE X.

Area No.	Spark gap.	P. K. V.	Time in seconds.
1	2	42	5.50
2	3	56	3.00
3	4	70	2.00
4	5	84	1.33
5	6	98	1.00
6	2	42	2.00
7	3	56	2.00
8	4	70	2.00
9	5	84	2.00
10	6	98	2.00

Develop the film until the lightest area, No. 6, shows some blackening. Rinse, fix, wash, and dry it.

Discussion.—As in the preceding experiments, the first five areas will be of approximately the same degree of blackening, while areas 6 to 10 will progressively increase in density. In exposing the first five areas, the voltage is changed 14 kilovolts (1-inch spark gap) for each area, but there is a corresponding decrease in the time to compensate for the increased voltage. The times used have about the same ratio to each other as the numbers 17.5, 31, 49, 70, and 96, which are the same as the squares of the voltages. If each of these numbers is multiplied by the time of the corresponding exposure, the result will be between 93 and 98, it being impossible to secure measurements of the exact time for these voltages. This part of the experiment shows that the intensity of the Roentgen-ray exposure does vary directly as the square of the voltages measured in peak kilovolts.

In the last five areas, the time is kept constant so that an increase in the density of the film from area 6 to area 10 would be expected. These densities should have the same ratio as the squares of the voltages used in producing them.

The inverse-square law with reference to anode-film distances holds true for all Roentgen-ray exposures. For this reason, it is a very valuable law—one that permits of a reference chart being made by calculation only. The law governing variations in intensity produced by variations in voltage is approximately correct for exposures made with plates and films without intensifying screens. When intensifying screens are used, however, the law becomes inoperative. For this reason, when films and screens are used, the preparation of a chart by calculations for reference in roentgenography is impossible.

The selection of the voltage to be used must be based on the thickness and density of the part being examined and on the total quantity of rays, the latter depending on time, milliamperage, and anode-film distance. When using intensifying screens, to shorten the time of an exposure, it is usually preferable to decrease the distance and increase the milliamperage. However, it is occasionally necessary and often is advisable to shorten an exposure more than can be done by increasing milliamperage and decreasing distance. It then becomes necessary to increase the voltage. It is also occasionally desirable to increase the contrast on Roentgen-ray films by decreasing the voltage producing the rays, which will

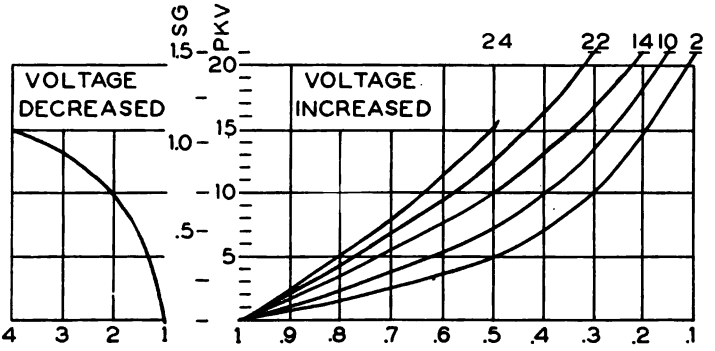

FIG. 39.—A chart showing the changes in exposures permitted by changes in voltage. The ordinates on the left of the middle of the chart are voltage values both as spark gap in inches and as peak kilovolts. The curve at the left of the chart is used when the voltage is to be decreased; the curves on the right when the voltage is increased. The abscissæ at the bottom of the chart are factors for determining the proper exposure when voltage changes have been made. The explanation of the use of this chart is given in the text.

require an increase in the time of the exposure. That these changes may be made intelligently, a chart for reference is essential. Such a chart is shown in Fig. 39.

The effects of voltage changes on Roentgen-ray exposures graphically shown by this chart were determined by experimental exposures through paraffin blocks. In Chapter VII a basic exposure technique is described in which is used a quantity of Roentgen-rays represented by 20 milliamperes for five seconds at a 35-inch anode-film distance, with a voltage appropriate for the thickness of the part being examined. The chart was specially designed to be used with this technique, but the essential features of it may be used with any technique.

The ordinates on the left of the middle of the chart show voltage

values both as spark gap in inches and as peak kilovolts. The curve on the left is used if the voltage is to be decreased; the curves on the right if the voltage is to be increased. The figures at the ends of the curves along the upper right margin of the chart indicate the lower limits of thicknesses of parts in centimeters appropriate for the voltage increases shown by that curve. The abscissæ at the bottom are the factors for multiplying the time, milliamperes, or the milliampere-seconds to obtain the correct exposure with the added voltage.

A decrease in voltage produces a constant change in the exposure. For example, it is shown by the chart that a decrease in voltage of 10 peak kilovolts ($\frac{3}{4}$-inch spark gap) will require a doubling of the exposure, while a decrease of 15 peak kilovolts (1-inch spark gap) requires that the exposure be multiplied by four.

The increase in voltage required to shorten an exposure is variable, and is governed by the thickness of the part to be examined, thinner parts requiring less voltage increase than thicker parts. This fact makes necessary different curves for different thicknesses. The bottom curve on the right of the chart with the figure 2 at its end is to be used for thicknesses from 2 centimeters to the number at the end of the next curve, which is 10, the second curve to be used for thicknesses between 10 and 14 centimeters, etc. For example, the chart shows that the addition of 10 peak kilovolts ($\frac{3}{4}$-inch spark gap) to the voltage required for a part between 2 and 10 centimeters thick will reduce the exposure to 0.3 of its original value; that the same addition to a voltage required for a part between 10 and 14 centimeters in thickness will reduce the exposure to 0.4; the same addition to a voltage appropriate for parts between 14 and 22 centimeters in thickness will reduce the exposure to 0.5 of the original or known exposure, and that voltage additions for thicker parts have still less effect on the exposure.

From this chart the two outstanding facts that should be remembered are that the subtraction of 10 peak kilovolts or its equivalent requires a doubling of the exposure time and that the addition of 10 peak kilovolts will, in a majority of instances, permit of a reduction of the exposure time one-half.

The only published figures on the effect of voltage changes on the time of exposures when using intensifying screens that have been found are those of Files. His chart differs from Fig. 39 in that the effects are shown to be the same, irrespective of the thickness of the part being examined, and that a somewhat greater voltage range

is included. The effects of the more commonly used voltage changes as shown on the two charts are the same.

These charts show the importance of voltage as one of the factors in roentgenographic exposures. Slight errors in time or milliamperage will have but little effect on films, while similar errors in voltage will have a more pronounced effect. From the chart it may be seen that using a voltage that is 7 peak kilovolts or ½-inch spark gap too high will cause an overexposure of from 30 to 60 per cent; using a voltage that is the same amount too low will cause approximately 50 per cent underexposure. Fortunately there is a latitude in Roentgen-ray films which allows of some under or overexposure in films of good quality. Nevertheless, these facts make the selection of the proper voltage the most important part of each roentgenographic exposure. Dark-room manipulation possibly excepted, the mistake most often made in roentgenography is overexposure from the use of too high voltage resulting in too penetrating rays, to compensate for which the films are underdeveloped, with a consequent lack of both contrast and detail. Since this is true, too much emphasis cannot be put on the voltage determinations in Experiments 1 and 3, or upon the careful selection of the proper voltage for each exposure.

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CHAPTER VII.

A BASIC ROENTGENOGRAPHIC TECHNIQUE.

In laboratory procedures, an attempt should be made to reduce to a routine, as much as possible, all work that is done. If this is accomplished, many of the details tend, by repetition, to become reflex or automatic, leaving the mind free to think of those which cannot be included. Whenever it can be accomplished, it is also advisable to establish some basic method or foundation, from which, by changes in the different factors, all other proceedings may be derived. Roentgenographic work in a Roentgen-ray laboratory can be more or less reduced to a routine and readily permits of the adoption of a basic or fundamental method of making Roentgen-ray exposures. These phases of the subject will be discussed in this chapter.

In this discussion all of the components which enter into roentgenographic exposures must be included. These are:

1. The photographic material used.
2. The distance from the anode of the tube to the film.
3. The milliamperes of current through the tube.
4. The time of the exposure.
5. The voltage of the current applied to the tube.
6. The part of the body being examined, especially its thickness and roentgenographic density.

Of these, the distance, time, milliamperage, and voltage constitute the exposure factors—the distance, time, and milliamperage governing the quantity and the voltage controlling the quality or penetrability of the Roentgen-rays used.

Of primary importance in this discussion is a decision as to the type of routine practice that should be adopted. It is obvious that one in which there is the least variation in the exposure factors would be preferable to any other. The many different kinds of Roentgen-ray exposures make it impossible to select one factor and vary it, keeping the others constant, so that the best procedure would be to select one as the chief variable factor and change it more often than any of the others. Since it is the differences in thickness and

roentgenographic density of the parts of the body requiring examination that necessitates variations in exposures, it would seem that the factor most nearly compensating for these differences should be selected as the one to be most often varied. Inasmuch as the voltage governs the penetrability of the rays—long rays of low penetrating power, produced by a low voltage, for thin parts, and shorter, more penetrating rays, produced by a higher voltage, for thick or dense parts—in a basic roentgenographic technique the voltage should be the chief variable factor.

With the voltage to be varied according to the thickness and density of the part being examined, what values may be given the other exposure factors and what photographic material is to be selected for a basic roentgenographic exposure technique?

By adopting one form of photographic material and using it for all examinations, this component can at once be eliminated. Double-coated films and double intensifying screens in suitable cassettes have distinct advantages over all other forms. Using them, exposures can be made with a much smaller quantity of rays; more contrast can be obtained than with films alone; they are especially adapted to rapid exposures; they make possible the use of a Potter-Bucky diaphragm, and, except for intraoral films of the teeth, they can be used for all examinations. For these reasons, they should be selected as photographic material.

Less distortion and better detail on Roentgen-ray films can be secured with the longest practicable anode-film distance. At the longer distances the rays do not diverge so much between the structures being examined and the film, thus making the images more nearly the exact size and shape of the structures themselves. Also, at the longer distances the focal spot of the tube, compared to the film surface, approaches more nearly a point, thus increasing detail on the films. Since most tube stands are made so that the tube anode may be elevated from 35 to 40 inches above the top of the table, 35 inches seems a suitable distance to select.

There are a number of different combinations of milliamperage and exposure time that could be selected. From these, 20 milliamperes of current through the tube and a five-second exposure time have been chosen. Twenty milliamperes is within the capacity of all Coolidge tubes, except the 10-milliampere radiator type. Five seconds is not too long to be tiresome to the patient; it is long enough to permit necessary corrections in tube current; it is within the capacity of all timing devices, and it may be accurately measured

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4. The time of the exposure.
5. The voltage of the current applied to the tube.
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Of these, the distance, time, milliamperage, and voltage constitute the exposure factors—the distance, time, and milliamperage governing the quantity and the voltage controlling the quality or penetrability of the Roentgen-rays used.

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With the voltage to be varied according to the thickness and density of the part being examined, what values may be given the other exposure factors and what photographic material is to be selected for a basic roentgenographic exposure technique?

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4. The time of the exposure.
5. The voltage of the current applied to the tube.
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roentgenographic density of the parts of the body requiring examination that necessitates variations in exposures, it would seem that the factor most nearly compensating for these differences should be selected as the one to be most often varied. Inasmuch as the voltage governs the penetrability of the rays—long rays of low penetrating power, produced by a low voltage, for thin parts, and shorter, more penetrating rays, produced by a higher voltage, for thick or dense parts—in a basic roentgenographic technique the voltage should be the chief variable factor.

With the voltage to be varied according to the thickness and density of the part being examined, what values may be given the other exposure factors and what photographic material is to be selected for a basic roentgenographic exposure technique?

By adopting one form of photographic material and using it for all examinations, this component can at once be eliminated. Double-coated films and double intensifying screens in suitable cassettes have distinct advantages over all other forms. Using them, exposures can be made with a much smaller quantity of rays; more contrast can be obtained than with films alone; they are especially adapted to rapid exposures; they make possible the use of a Potter-Bucky diaphragm, and, except for intraoral films of the teeth, they can be used for all examinations. For these reasons, they should be selected as photographic material.

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There are a number of different combinations of [illegible] exposure time that could be selected. For the 5 milliamperes of current through the tube and a [illegible] have been chosen. Twenty milliamperes is the capacity of all Coolidge tubes, except the [illegible] seconds is not too long to be [illegible] to permit [illegible] capacity of [illegible]

without a timer. The milliamperage and time combined as milliampere-seconds represent a relatively large quantity of rays with which a voltage may be used sufficiently low to give considerable contrast on the films. A milliampere-seconds value of 100 gives a number with which calculations of exposures derived from the basic technique can be made more easily than with any other.

In a basic roentgenographic method of this sort, with the other three factors constant, the penetrability or quality of the rays (governed by the voltage of the current applied to the tube), is to be the chief variable factor, the variations in the voltage being determined by the thicknesses and densities of the parts of the body being examined. Thicknesses of parts of the body, from a minimum of 1 centimeter in the fingers and toes to a maximum of 35 centimeters through the lumbosacral region in a lateral direction, are encountered. The measurement of the thicknesses of the parts, either with a ruler or a pelvimeter, should present no difficulties.

The measurements should be made usually through the thickest portion of the part to be examined. For example, through the patella for an antero-posterior exposure of the knee, and through the middle portion of the abdomen for most of the abdominal structures. Since a change in posture, the application of compression bands, etc., may cause a considerable change in thickness, measurements usually should be made after the patient is in position for the exposure. Also they should be made in the direction traversed by the central rays from the tube. This is especially important when exposing oblique views such as those of the mandible, mastoids, or nasal accessory sinuses.

The roentgenographic density of parts of the body, by which is meant their ability to absorb Roentgen-rays, is variable. As a general statement it may be said that three kinds of roentgenographic density are encountered. These include what may be called average density—that of the abdomen, pelvis, hips, shoulders, neck, and extremities; the density of the thorax through the lungs, and the density of the structures of the head and skull. Except the lungs and head, all parts of the body are of virtually the same density. Slight variations do exist. The extremities of a muscular person may be slightly more dense than those of the same thickness of a fat person; the density of the tissues of a child is less than that of an adult; the density of the upper part of the abdomen through the liver is greater than that of the middle portion; while most marked is the diminished density of the tissues produced by atrophy

from disuse and that due to age. However, in selecting exposure factors for a basic technique, it may be stated, that, except for the lungs and skull, rays of a quality suitable for a certain thickness of tissue will be appropriate for that thickness wherever it may be found, taking as a basis the average density of tissues of healthy adults. Therefore, using a quantity of rays represented by 100 milliampere-seconds at a 35-inch anode-film distance, a basic roentgenographic technique may be completed by selecting a suitable voltage, giving rays of appropriate quality for each thickness of tissue encountered, stopping, of course, when the highest voltages permitted by Coolidge tubes have been reached.

The determination of the relationship between voltage and thicknesses of tissue of average density is the most important part of the development of a basic roentgenographic technique. This may be done by trial exposures—making several exposures through a part of the body of a certain thickness using different voltages, developing the films for the full time at the proper temperature, and selecting the voltage that gives a good result. This is time consuming, requires the use of considerable material, and, what is more important, necessitates multiple exposures either of the same or of different persons. Exposures through some substance that has the same absorbing power for Roentgen-rays as human tissue of average density would be much simpler and would answer the purpose quite as well. Paraffin has this property, so that paraffin blocks of different thicknesses may be used to determine experimentally the thickness-voltage relationship for a basic roentgenographic technique.[1]

The results of experiments of this kind, showing the relationship between thickness and voltage, have been incorporated in a chart, called a thickness-voltage chart, which is shown in Fig. 40.

In the experiments on which this chart is based, a constant distance, milliamperage, and time were employed, using those selected as being most appropriate for a basic technique. All exposures were made on Eastman superspeed films, using Patterson double intensifying screens. The voltage determinations were made with a sphere gap, and, to eliminate errors from fluctuations, were carefully checked during the experiments. The films were developed in fresh developer, for full time, at the proper temperature.

The ordinates of the thickness-voltage chart are the voltage

[1] The idea of using paraffin for this purpose was obtained from reading of its use as an absorbing medium for the determination of depth doses in Roentgen therapy.

values expressed as spark gap in inches and as peak kilovolts, arranged in steps of 7 peak kilovolts and ½-inch spark gap. Although not included in the ordinates, voltage values of 3½ peak kilovolts and ¼-inch spark gap, corresponding to the most common voltage intervals in the secondary circuits of Roentgen-ray machines, may be obtained easily from the chart. The total voltage extends from 42 to 98 peak kilovolts or from a 2- to a 6-inch spark gap.

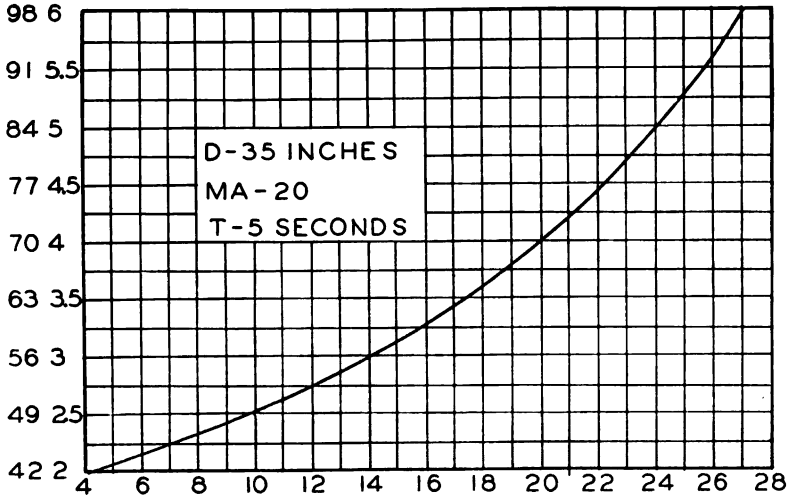

FIG. 40.—The thickness-voltage chart. The ordinates are voltage values both as peak kilovolts and spark gap in inches; the abscissæ are thicknesses of parts of the body in centimeters.

The abscissæ of the chart represent thicknesses of tissue from 4 to 27 centimeters. Thicknesses of tissue of less than 4 centimeters are encountered in the hands and toes for which 42 peak kilovolts (2-inch gap) are usually appropriate. This is true because the longest of the useful Roentgen-rays are produced by about 42 peak kilovolts, rays longer than these not being penetrating enough to pass through the glass bulb of the tube, the filter, the front of the cassette, and the uppermost intensifying screen. For the thinnest parts, if 42 peak kilovolts give overexposed films or if a voltage as low as this cannot be obtained from the machine, the time of the exposure may be shortened to four, three, or even two seconds. The antero-posterior thickness of the body rarely exceeds 27 centimeters. Should a person be encountered who is thicker than this, by the use of compression, the total thickness traversed by the rays can be

reduced to within the limits of the chart. The transverse or lateral thickness of the abdomen often exceeds 27 centimeters which requires the use of a relatively high voltage and a material increase in the time of the exposure. This will be considered in detail in a later chapter.

In the thickness-voltage chart it is interesting to note that voltages between 42 and 56 peak kilovolts (2- and 3-inch spark gap) cover a range of tissue thicknesses increasing from 4 to 14 centimeters, and that in the higher voltages the range of tissue thicknesses for similar voltages rapidly decreases, so that between 84 and 98 peak kilovolts (5- and 6-inch gap) the tissue range is but 3 centimeters. The voltage given for each tissue thickness is the average that should be used with that particular thickness. Since the percentage of error caused by using a voltage that is very slightly too high is about the same as that for one that is the same amount too low, should the exact voltage for a certain thickness not be obtainable on the machine, other factors must determine the voltage to be used. For instance, if the patient is a healthy muscular adult and the film is being made to show bone structures, the next higher voltage should be used; if the patient is young, feeble, has been ill for some time, or the soft tissue rather than the bone is desired, then the next lower voltage should be used.

As discussed in the preceding paragraphs, a basic roentgenographic technique may be devised by adopting double-coated films and double intensifying screens as photographic material, an anode-film distance of 35 inches, 20 milliamperes of current for five seconds time, with the voltage varied according to the thickness of the part being examined, and determined before the exposure from a chart prepared for that purpose. This technique is simple; it has one chief variable factor, and it allows of the selection of the factors before exposures with such a degree of accuracy that the results can be predicted. It depends on the thickness and relative density of the part being examined and not on the size or weight of the patient, thus eliminating the hypothetical man of average size weighing 150 pounds who has been used for years in determining sets of factors for roentgenographic exposures. As will be shown in a following chapter, by necessary modifications of the different exposure factors in this basic technique according to the laws which govern Roentgen-ray exposures, almost all roentgenographic technique can be derived from this basic method.

Experience leads to the belief that the thickness-voltage chart

given in Fig. 40 will be found correct for most Roentgen-ray installations. This statement presumes that the machines have been calibrated in a manner similar to that given in Experiments 1 and 3 with a sphere gap corrected for altitude, or with a point gap at not too high an altitude; that intensifying screens are of the same speed as those used in making the chart; that the machines with which it is used have voltage steps in the secondary circuit of 3½ peak kilovolts (¼-inch spark gap) or less; and that the supply-line current, transformer design, rectifier, measuring instruments, Roentgen-ray tube, etc., are such that the Roentgen-ray output for the various voltages and milliamperages, both in quantity and quality, is the same as that of the machine used in making the chart and of those with which it has been successfully used. If it is found by trial that this thickness-voltage chart does not give good results with a Roentgen-ray installation, to use this basic technique, a chart suitable for such an equipment must be made by experimental exposures through paraffin blocks. The manufacture of the blocks and the required experiments have been described in the next chapter under the heading of "Advanced Experiments."

To become familiar with the use of the thickness-voltage chart and the basic roentgenographic technique as here advocated, study the chapter on "Practical Exposure Technique." In this chapter are given the modifications of the basic technique that have been found necessary for exposing films of different regions of the body under the varying conditions which exist when such exposures must be made. Except in a few instances, in which it is not applicable, the thickness-voltage chart is used throughout.

To test the chart, make exposures of different regions of the body, using the technique advocated for each particular part. Measure the thickness of the part to be examined either with a centimeter ruler or with the centimeter scale on a pelvimeter and select from the chart the voltage for that thickness. In making these trial exposures, make use of the tables and charts prepared during the performance of Experiments 1 and 3, being especially careful when using more than 20 milliamperes to compensate for secondary voltage drop caused by the increase in milliamperage. Inasmuch as this technique is based on the standard development of the films, any deviation from this will not give correct results.

If a study of the finished films shows them to be of good quality, the chart may be used as given and the advanced experiment omitted. If the films are not of good quality, if the thickness-

voltage chart is not applicable to a Roentgen-ray equipment, then a set of paraffin blocks should be made, the advanced experiments performed, and a chart prepared which is appropriate for that equipment. If this is done, the chart will be correct for that particular installation, with its own accessories and operating under its own peculiar conditions.

Unfortunately the basic technique as outlined in the preceding pages is not applicable to some Roentgen-ray machines. Those for which it is not suited include machines having larger steps in the secondary voltage than 3½ peak kilovolts, those in which the introduction of the rheostat to secure such steps causes so much irregularity in the secondary voltage that better results can be obtained without it, and, as a general rule, many unit type and valve-tube machines used for roentgenography. For these, the same advantages follow the use of a routine procedure and a basic technique, but a different technique, based on the same general principles, must be devised.

If the construction of the control devices in the primary circuit is not such that the required number of voltage steps can be obtained to make the voltage the chief variable factor, then a second factor must be selected to be varied with the voltage. This second variable factor should be the time of the exposure. A basic technique with two variable factors, the voltage and the time, may be devised in much the same manner as one in which the voltage is the only variable factor, and the results incorporated in an exposure chart. One of this kind is shown in Fig. 41.

The machine for which this chart was made has an autotransformer with 20 steps and a 15-step rheostat, with only 6 of the autotransformer steps giving voltages within the range of those useful in roentgenography. With 20 milliamperes, on button 1 the peak kilovoltage is 50; on button 6 it is 94, there being steps of approximately 8 kilovolts between buttons. An attempt to use smaller steps by the use of the rheostat caused so many irregularities in the secondary voltage that the attempt was abandoned and a different basic technique devised for this machine. With it there is also a lower Roentgen-ray output than with any other machine of similar type that has been tested. A voltage of 84 peak kilovolts is required, the other factors being constant, to give the same Roentgen-ray output produced by 70 kilovolts on other machines. Although having operating characteristics differing from others, a special basic technique was devised for this machine and, by means of

experimental exposures through paraffin blocks, the chart in Fig. 41 was made. The use of this technique and this chart on this machine gives good results.

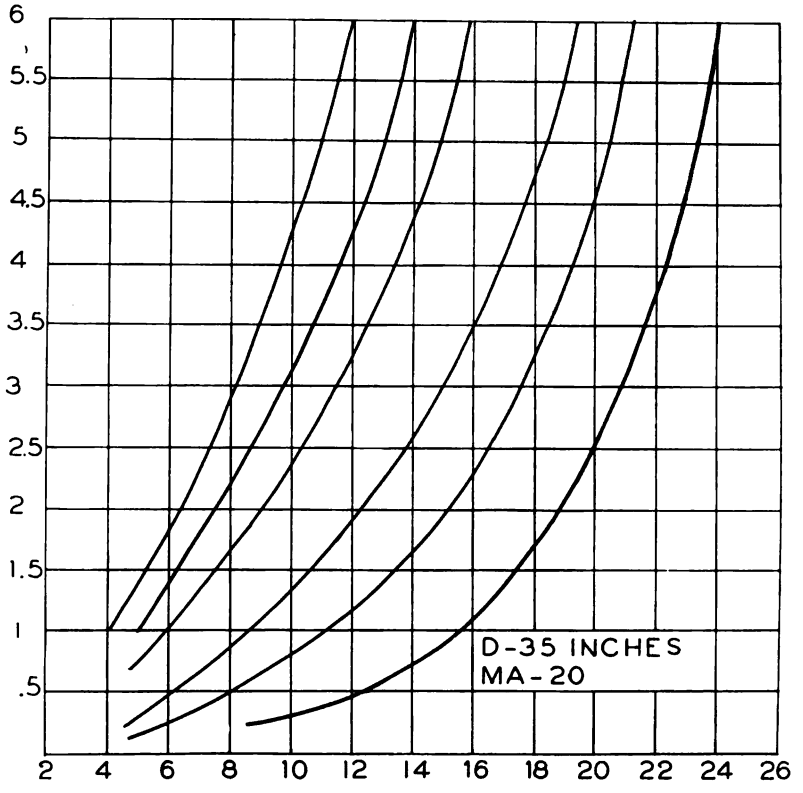

FIG. 41.—An exposure chart made by experimental exposures through paraffin blocks for a Roentgen-ray machine with six voltage selections, the chart showing a curve for each voltage. The ordinates are exposure times in seconds; the abscissæ are thicknesses of parts in centimeters. The constant factors are an anode-film distance of 35 inches and 20 milliamperes.

Other combinations than the one recommended, with different constant and variable factors, may be used with equal success in a basic technique as long as the principles underlying the method of selecting and using the combinations are observed. For example, Jerman recommends the use of the 10-milliampere radiator type tube for roentgenography of all parts permitting of immobilization and a long exposure time. Because of the small focal spot, better

detail can be secured than by the use of any other Coolidge tube. Its use, however, necessitates two sets of exposure factors with different variables. In one, especially for films of the extremities, the milliamperes, time, and distance may be kept constant and the voltage varied according to thickness. For thicker parts, such as the vertebral column and pelvis, limiting the exposure time to five seconds would require a voltage higher than that permitted by the tube. This would necessitate a second set of exposure factors, especially for thick parts, in which the voltage, milliamperage, and distance are the constant factors with the exposure time varied to suit the thickness.

Exposure charts for a technique of this kind can be made easily. For the first set of factors a thickness-voltage chart can be prepared; for the second set a chart can be made using 10 milliamperes, a voltage of 85 peak kilovolts, and constant distance, with the time of the exposure varied to suit the thickness of the part to be examined (see Figs. 41 and 45). These charts can be made by experimental exposures through blocks of paraffin according to the methods given in Chapter VIII.

The kinds of technique and exposure charts that can be used with unit type machines are discussed in Chapter X.

In this chapter have been introduced the ideas of adopting a basic method of making roentgenographic exposures and of developing charts from which the proper factors for each roentgenographic exposure may be obtained. These are based on the thickness and density of the parts of the body to be examined and not on the size or weight of individual patients. One basic technique is given in detail, from which, as will be given later, by modifications of the various factors, practically all roentgenographic technique may be derived. It is believed that this type of technique is fundamentally sound and that, by its adoption and use, better results can be obtained than by the use of any other method.

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CHAPTER VIII.

ADVANCED EXPERIMENTS.

THE objects of the introductory experiments were to study the electric currents of a Roentgen-ray machine and the laws of roentgenographic exposures, and to teach familiarity with the details of the operation of a Roentgen-ray equipment. The objects of the advanced experiments are to teach a method of photographically measuring the Roentgen-ray output of a Roentgen-ray machine, to make a determination of the relationship between thickness and voltage, and to prepare a thickness-voltage chart as described in the preceding chapter. There will also be included general instructions for making experimental exposures through paraffin blocks to determine the exposure factors in a basic technique for equipments with which the thickness-voltage chart cannot be used.

PARAFFIN BLOCKS.

It has been found that paraffin has about the same absorbing power for Roentgen-rays as human tissue of parts of the body other than the thorax through the lungs and the skull. The absorbing power is not exactly the same, that of paraffin being slightly less than that of human tissue. They are so nearly alike, however, that a set of roentgenographic exposure factors that will give an image on a photographic emulsion of slightly greater than average density (see page 138) through a given thickness of paraffin will give an image of average density through most parts of the human body of the same thickness.

For this reason exposures through blocks of paraffin may be used experimentally to duplicate actual working conditions in a Roentgen-ray laboratory. By their use almost any roentgenographic problem may be experimentally worked out. Paraffin blocks have been used in testing the speed of intensifying screens, in determining the absorption of the grids of Potter-Bucky diaphragms, in examining new photographic materials, and in teaching students and technicians. Of greater importance is their use in measuring the Roent-

gen-ray output of a Roentgen-ray machine and in determining sets of exposure factors and devising exposure techniques that can be used as a basis for practical roentgenography. Because of their usefulness, a set of paraffin blocks is a very valuable addition to any Roentgen-ray laboratory.

Our first experiments were made with ordinary commercial paraffin in blocks 1.6 centimeters thick, as it comes in pound packages from the grocer. A set of thirty-five blocks each 1 centimeter thick were next made which melted into a shapeless mass during the first hot weather. The set now in use was made of

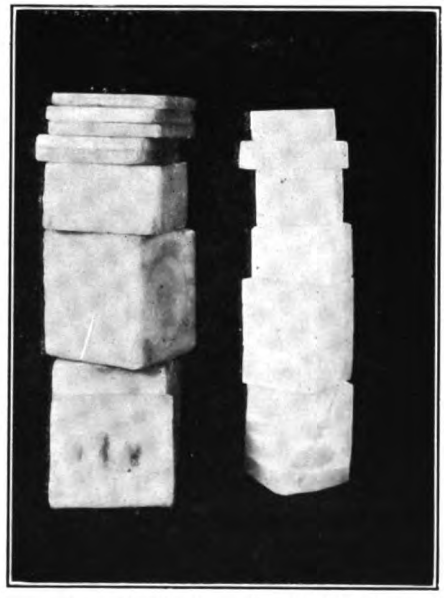

FIG. 42.—Two sets of paraffin blocks as described in the text. In the larger set the 2-cm. block containing the teeth is standing on edge at the bottom of the pile.

paraffin of a high melting point bought from a laboratory supply house. It consists of two blocks that are 10 centimeters thick, one that is 5 centimeters thick, two that are 2 centimeters thick, and six that are 1 centimeter thick (Fig. 42). With this set any thickness from 2 to 35 centimeters can be secured. It has been in use for some time at all seasons of the year and has proved entirely satisfactory.

A set of blocks for temporary use can be made easily and quickly from commercial paraffin. A permanent set, however, should be

made of paraffin with a higher melting point. For the former, 3 pounds are required. It is sold in packages, in blocks 13 centimeters long, 6.5 centimeters wide, and 1.6 centimeters thick, four blocks to the pound, or twelve blocks in 3 pounds. Each of these should be cut into halves transversely through the middle of the blocks. Two blocks each 8 centimeters thick should be made from ten of these smaller pieces. This can be done by passing the blocks through a flame until the surface is melted and then pressing them together. Four other blocks will be required, two that are 2 centimeters thick, and two that are 4 centimeters thick. The former may be made by

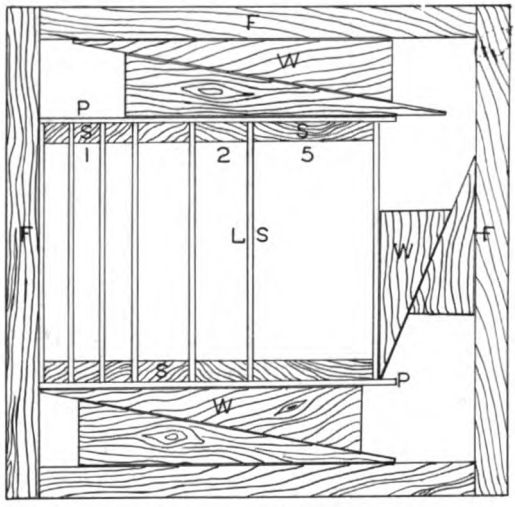

FIG. 43.—Vertical view of a simple collapsible mold for making paraffin blocks by the method described in the text.

sticking two of the pieces together and shaving off the paraffin to the desired thickness; the latter by sticking three of the blocks together and shaving off one side until the desired thickness is reached. If two pieces of heavy cardboard, as wide as the thickness of the blocks, are stuck to the sides and used as guides, the shaving off of the blocks to the desired thickness can be accurately done. A set of blocks of this kind will give any thickness, from 2 to 28 centimeters, in steps of 2 centimeters. To cast an image on the film when used, three teeth should be put into one of the 2-centimeter blocks (see page 130).

In making a permanent set of blocks from paraffin of a higher melting point, a simple mold like the one illustrated in Fig. 43 may

be used. This consists of a framework (F) of ½-inch boards, 2½ to 3 inches in height. The mold proper is made of two cleaned 5- by 7-inch photographic plates (P) which form its sides, the partitions being made of cleaned lantern slide plates (L S), held apart by wood separators (S), which are as wide as the desired thickness of the blocks. The mold is held together by three square wedges (W) and rests on an 8- by 10-inch cleaned photographic or Roentgen-ray plate. To prevent the paraffin from sticking, the glass parts of the mold should be rubbed with motor oil or petrolatum before it is assembled.

The paraffin is heated in a suitable container until it is melted. Before it is poured into the mold, it is allowed to cool to a temperature just above the melting point. This cooling is important, for very hot paraffin will run through the cracks of the mold, and the contraction resulting from its cooling will cause large defects in the blocks. When the paraffin has solidified, the mold is broken apart and the blocks removed. Minor defects may be filled in by pouring melted paraffin into them and smoothing the surface with a heated glass plate.

To produce an image, two or three teeth should be put into one of the 2-centimeter blocks. A single, a double, and a three-rooted tooth, each containing defects and fillings to produce detail in their images on the films, have been found satisfactory (Fig. 44). Holes slightly larger than the teeth should be cut in the block, the teeth placed in them, and the holes filled with melted paraffin. The two kinds of sets of paraffin blocks, the manufacture of which has been described, are shown in Fig. 42.

In all experimental exposures, the block containing the teeth should be placed nearest the film.

In the experiments which follow, detailed instructions are given for performing the experimental exposures necessary in making a thickness-voltage chart. These are especially intended for those Roentgen-ray machines that have a mechanical rectifier and have been calibrated in a manner similar to that given in Experiments 1 and 3, for Roentgen-ray machines with valve-tube rectification for which a calibration chart giving the same information is supplied by the manufacturers, and they may be used also with unit type machines on which voltage intervals of ¼-inch spark gap or 3½ peak kilovolts can be obtained in the secondary circuit. A voltage higher than a 5-inch gap or 85 peak kilovolts should not be used with a radiator type tube; if such a tube or a unit type machine is used, Experiment 9 should be omitted.

made of paraffin with a higher melting point. For the former, 3 pounds are required. It is sold in packages, in blocks 13 centimeters long, 6.5 centimeters wide, and 1.6 centimeters thick, four blocks to the pound, or twelve blocks in 3 pounds. Each of these should be cut into halves transversely through the middle of the blocks. Two blocks each 8 centimeters thick should be made from ten of these smaller pieces. This can be done by passing the blocks through a flame until the surface is melted and then pressing them together. Four other blocks will be required, two that are 2 centimeters thick, and two that are 4 centimeters thick. The former may be made by

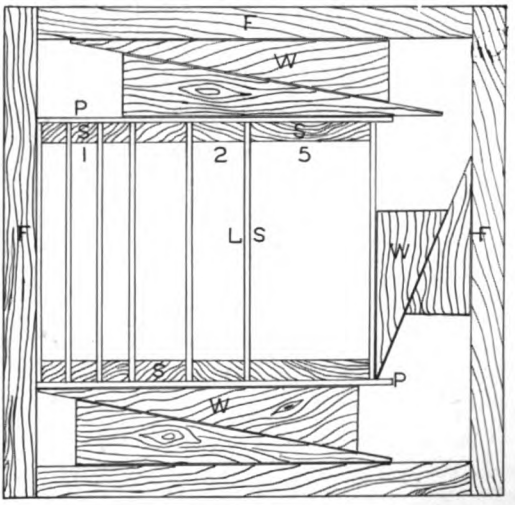

FIG. 43.—Vertical view of a simple collapsible mold for making paraffin blocks by the method described in the text.

sticking two of the pieces together and shaving off the paraffin to the desired thickness; the latter by sticking three of the blocks together and shaving off one side until the desired thickness is reached. If two pieces of heavy cardboard, as wide as the thickness of the blocks, are stuck to the sides and used as guides, the shaving off of the blocks to the desired thickness can be accurately done. A set of blocks of this kind will give any thickness, from 2 to 28 centimeters, in steps of 2 centimeters. To cast an image on the film when used, three teeth should be put into one of the 2-centimeter blocks (see page 130).

In making a permanent set of blocks from paraffin of a [illegible] melting point, a simple mold like the one illustrated [illegible]

be used. This consists of a frame of 1" x 2" pine boards 2 to 3 inches in height. The mold proper is made of two pieces 8 to 9 inch porcelain plates P which form the sides, the parts being made of heated mirror side plates 1/8 inch apart by wood separators S, which are as wide as the desired thickness of the blocks. The mold is held together by three square weights W and rests on a 9 x 12 inch heated photographic or Roentgen-ray plate. To prevent the paraffin from sticking, the glass parts of the mold should be rubbed with mineral oil or petrolatum before it is assembled.

The paraffin is heated in a suitable container until it is melted. Before it is poured into the mold, it is allowed to cool to a temperature just above the melting point. This cooling is important, for very hot paraffin will run through the cracks of the mold, and the contraction resulting from its cooling will cause large defects in the blocks. When the paraffin has solidified, the mold is broken apart and the blocks removed. Minor defects may be filled in by pouring melted paraffin into them and smoothing the surface with a heated glass plate.

To produce an image, two or three teeth should be put into one of the 2-centimeter blocks. A single, a double, and a three-rooted tooth, each containing defects and fillings to produce detail in their images on the films, have been found satisfactory (Fig. 44). Holes slightly larger than the teeth should be cut in the block, the teeth placed in them, and the holes filled with melted paraffin. The two kinds of sets of paraffin blocks, the manufacture of which has been described, are shown in Fig. 42.

In all experimental exposures, the block containing the teeth should be placed nearest the film.

In the experiments which follow, detailed instructions are given for performing the experimental exposures necessary in making a thickness-voltage chart. These are especially intended for those Roentgen-ray machines that have a mechanical rectifier and have been calibrated in a manner similar to that given in Experiments 1 and 3, for Roentgen-ray machines with [illegible] rectification for which a calibration chart giving the sam[illegible]tion is supplied by the manufacturers, and they may be [illegible] with unit type machines on which [illegible]ltage intervals of [illegible] gap or 3½ peak kilo[illegible] can be [illegible] the second [illegible] A voltage higher t[illegible] [illegible]ak kilo[illegible] [illegible]t be used with a [illegible] a tub[illegible] [illegible]e machine is used, [illegible]itte[illegible]

Experiment 7.

Object.—To determine the thicknesses of paraffin appropriate for the quality of Roentgen-rays produced by a voltage equivalent to a 2- and 3-inch spark gap between points, or 42 and 56 peak kilovolts.

In this and the succeeding experiments, the other exposure factors should be those selected for the basic technique. Use a double-coated film in either a 6½- by 8½- or 8- by 10-inch cassette fitted with good double intensifying screens. With a wax pencil, mark off the face of the cassette into 10 areas, similar to the film exposure holder used in the earlier experiments. Number these areas from 1 to 10. The anode-film distance should be kept constant at 35 inches. Each exposure is to be of 20 milliamperes for five seconds. Use a small cone. Do not fail to number the film at the time of the exposure with a lead number. That they may be identified, it is also advisable to number at least two of the areas.

Make the exposures using a 2-inch spark gap or 42 peak kilovolts for the first five areas and a 3-inch spark gap or 56 peak kilovolts for the last five areas and paraffin blocks of the thicknesses indicated in the following table:

Table XI.

Area No.	Paraffin thickness, cm.	Area No.	Paraffin thickness, cm.
1	2	6	10
2	4	7	12
3	6	8	14
4	8	9	16
5	10	10	18

When the exposures have been completed, carefully develop the film. This should be done in a safe dark room, with fresh developer at a temperature of 65° F. for full five minutes, regardless of the appearance of the images on the film. Following the development, the film should be carefully fixed and thoroughly washed and dried. There should be no variation from this standard dark-room manipulation, for doing so will detract from the quality of the film. The exposed film will look like the one shown in Fig. 44.

When the film is dry, put it in a good illuminator and study it carefully. Examine all of the images with particular attention to density, detail, and contrast (see Chapter IX). Select the one slightly denser than would be considered best for both voltages. These selections will give the thicknesses of paraffin in centimeters

most appropriate for the quality of rays produced by these two voltages. Mark the selection on the film. Inasmuch as it will be used later in preparing the thickness-voltage chart, this film should be carefully preserved.

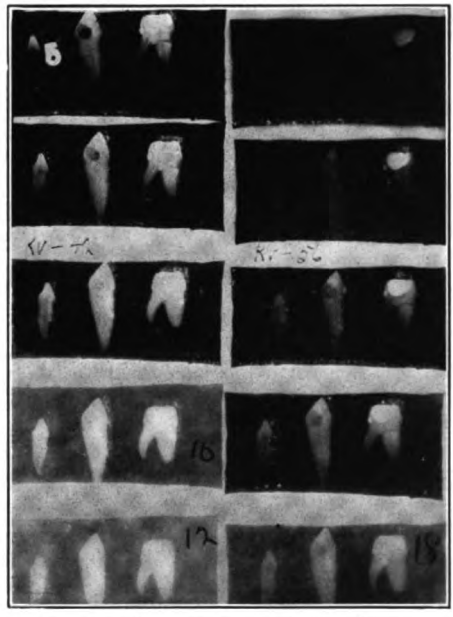

FIG. 44.—A reproduction of a film used in experimental exposures through paraffin blocks.

EXPERIMENT 8.

Object.—To determine the thicknesses of paraffin appropriate for the quality of Roentgen-rays produced by a voltage equivalent to a 4- and 5-inch spark gap between points, or 70 and 85 peak kilovolts.

This experiment is performed exactly like Experiment 7. The lower voltage is used for the first five areas; the higher voltage for the areas from 6 to 10. The thicknesses of paraffin for each voltage are given in the following table:

TABLE XII.

Area No.	Paraffin thickness, cm.	Area No.	Paraffin thickness, cm.
1	16	6	20
2	18	7	22
3	20	8	24
4	22	9	26
5	24	10	28

Develop and dry the film. Study it carefully and select the thicknesses of paraffin giving the best images for these voltages. Preserve the film for future use.

EXPERIMENT 9.

Object.—To determine the thickness of paraffin appropriate for the quality of rays produced by a voltage equivalent to a 6-inch spark gap between points or 98 peak kilovolts. Except that but five areas are exposed, this experiment is performed exactly as the preceding two experiments, using the paraffin thicknesses given in the following table:

TABLE XIII.

Area No.	Paraffin thickness, cm.
1	22
2	24
3	26
4	28
5	30

When this film is completed, the thickness of paraffin appropriate for the quality of rays produced by this voltage should be selected.

THE PREPARATION OF THE THICKNESS-VOLTAGE CHART.

In Experiments 7, 8, and 9, an attempt has been made to measure the quality of Roentgen-rays produced by different voltages through a Roentgen-ray tube, in terms of thicknesses of paraffin, when the quantity of rays is represented by 100 milliampere-seconds at a 35-inch anode-film distance. In these experiments, five thicknesses of paraffin have been selected as most appropriate for rays produced by five different voltages. These findings should now be incorporated in a thickness-voltage chart.

Beginning at the lower left-hand corner on a piece of cross-section paper, number the abscissæ along the bottom in centimeters from 4 to the number selected from Experiment 9. Number the ordinates along the left margin in the different voltage values, as in Fig. 40. On the paper, place a dot where the ordinates and abscissæ for the various voltages and paraffin thicknesses selected during the experiments cross each other. Connect these dots by an irregular curve and a preliminary thickness-voltage chart is completed.

EXPERIMENT 10.

Object.—To prove that the thickness-voltage chart has been correctly made.

If the thickness-voltage chart has been correctly made, it should be possible to select from it the voltage appropriate for any thickness of paraffin from the lowest to the highest that are represented. Although voltages for paraffin thicknesses between those in the experiments have not been determined, experience has taught that the chart should give them correctly. To prove this, expose another film as in the other experiments using voltages increasing in steps of ½-inch spark gap or the equivalent in peak kilovolts, as in the following table, making the exposures through the corresponding thicknesses of paraffin selected from the chart:

TABLE XIV.

Area No.	Spark gap in inches.	P. K. V.	Paraffin in cm. from the chart.	Area No.	Spark gap in inches.	P. K. V.	Paraffin in cm. from the chart.
1	2	42		6	4½	77	
2	2½	49		7	5	84	
3	3	56		8	5½	91	
4	3½	63		9	6	98	
5	4	70		10			

When this film has been completed, an examination of it should show all of the areas to have almost exactly the same density. Because the greater scattering of rays produced by the higher voltages in passing through the thicker masses of paraffin will diminish detail and contrast on those areas, detail and contrast will be better on the areas exposed with the lower voltages.

When the experiments have been completed, if the chart proves to be satisfactory, it is ready for use and may be pasted on a piece of cardboard, covered with a cleaned film, and mounted on the wall by the control cabinet.

Although the experiments detailed in this chapter are intended for Roentgen-ray machines that have been calibrated, and are for the specific purpose of making a thickness-voltage chart, similar experimental exposures through blocks of paraffin can be made with any Roentgen-ray machine using a Coolidge tube and the results incorporated in a chart that may be made the basis or foundation for a roentgenographic exposure technique. If exposures are made to determine a thickness of paraffin suitable for a certain voltage, the exposure factors should be kept constant and the thickness of

paraffin changed. On the other hand, if the time that will give a suitable exposure is being sought, the paraffin thickness and all the other factors should be kept constant, the time of the exposures being changed.

Among others, experimental exposures may be used under the following conditions:

1. A point-gap calibration of a Roentgen-ray machine made at any altitude may be used the same as an accurate calibration as long as the exposure chart is based on the actual Roentgen-ray output as determined by experimental exposures. In such instances it would be wise to determine the approximate value of the highest voltage so as not to exceed the capacity of the tubes being used.

2. With Roentgen-ray machines that are equipped with voltmeters but not with spark gaps and have not been calibrated and with those having valve-tube or kenetron rectifiers, voltmeter readings at regular intervals may be taken as the indicators of secondary voltage and the Roentgen-ray output for each voltmeter reading determined by experimental exposures. The voltmeter readings may be made the ordinates of the chart instead of the actual voltage values used in Fig. 40. Such voltmeter readings may be either in alternating current volts, in effective or peak kilovolts, or in the arbitrary divisions of a so-called potential indicator.

3. With a Roentgen-ray machine that has neither a voltmeter nor a spark gap and has not been calibrated, even the control settings may be used as indicators of secondary voltages, experimental exposures being made with control settings at regular intervals to determine the Roentgen-ray output, the control settings being made the ordinates of the exposure chart. If the primary current is variable, with a machine of this kind the best results cannot be expected with any sort of technique.

4. With Roentgen-ray machines that have steps in the secondary voltage of more than $3\frac{1}{2}$ peak kilovolts and which do not have a rheostat, or on which it is not advisable to use the rheostat, a chart like the one in Fig. 41 should be prepared. In experiments for a chart of this kind the voltage and the thickness of paraffin are kept constant, the time of the exposure being varied. The finished films are studied to determine the time that gives the optimum exposure, the exposure times in seconds being the ordinates of the exposure chart.

If experimental exposures through paraffin blocks are made with a Roentgen-ray machine that has not been calibrated in a manner

similar to that given in Experiments 1 and 3, as in 2, 3, and 4 above, it must be remembered that any change in milliamperage will cause a change in voltage which may require additional exposures to determine the effect of such changes on the Roentgen-ray output.

All experimental exposures through paraffin blocks should be carefully planned and outlined before they are attempted. A complete record of each experiment should be kept. A 4- by 6-inch card which may be attached to the finished film with a paper clip is suitable for this purpose. This card should show the number of the experiment which should agree with that on the film. It should also show the number of each exposed area and the exact details of the exposure of each area. In addition to the number of the area, these details include the anode-film distance, the milliamperage, the time of the exposure, the number of milliampere-seconds, the voltage applied to the tube, the voltmeter reading, and the total thickness of paraffin used. The records of each experiment and the exposed films should be carefully preserved for reference at any time in the future.

In any and all experimental exposures performed for the purpose of determining the Roentgen-ray output of a machine, the standard development of films should be followed (Chapter V). The developer should be fresh, the dark room and dark room lights safe, and development should be for the time required by the temperature of the solutions.

CHAPTER IX.

PRACTICAL EXPOSURE TECHNIQUE.

JUDGING THE QUALITY OF ROENTGENOGRAMS.

BEFORE undertaking a consideration of the different combinations of factors that may be used for different purposes in making roentgenographic exposures, it is advisable to discuss the properties which are considered in judging the quality of roentgenograms. When this has been done, the effects of the different exposure factors on the quality of films can be included. Density, contrast, detail, and amount of distortion are the properties considered in determining the quality of finished Roentgen-ray films.

By density is meant the degree of blackening of the films. It depends on the amount of the silver in the emulsion that has been affected and reduced to a metallic state; it is directly proportional to the quantity of rays which reach the emulsion and the fluorescent surfaces of the screens.

Variations in density may exist in a series of films and all of them be of good quality. The density of those of parts of the skeleton should be slightly greater than would be best for films of soft tissues. For example, the shadows of the kidneys will be more distinct on films of slightly less density than would be considered best for films of the adjacent lumbar vertebræ. As a rule, films of average density, neither too light nor too dark, are best for all purposes.

The density of Roentgen-ray films may be influenced in several ways. If a film with a greater density is desired, it may be obtained by increasing either the milliamperage, the time, the voltage, or by decreasing the anode-film distance. Of these, an increase in the voltage will have the most pronounced effect, but will also reduce contrast. If there are no contraindications, it is preferable to secure an increase in the density by increasing the time, or the milliamperage, or both. A decrease in density may be secured by decreasing the time, the milliamperage, or the voltage, or by increasing the distance. Probably the most common cause for too great a density (overexposure) is the use of too high a voltage. Since a decrease in voltage or an increase in distance will not only give a

diminished density, but will also increase contrast and detail, as a general rule such changes should be made when a decrease in density is desirable.

By contrast is meant the differences in density between the lighter and darker portions of the films. The best films are those which show considerable contrast. To produce marked contrast, a relatively low voltage and high milliampere-seconds must be used. Such voltage will produce rays of relatively longer wave-lengths and less penetrating power—rays that are well absorbed by the denser structures of the part so that their images will appear light on the films. The same rays will penetrate structures of less density and cause their shadows to be dark on the finished films.

If more penetrating rays produced by a higher voltage and requiring less quantity are used, the denser structures will not absorb so large a proportion of the rays and less contrast will result. Since contrast depends on the wave-lengths of the rays used, longer and less penetrating rays requiring a greater quantity, more contrast will be present on films exposed with the largest number of milliampere-seconds. The effect of using a decreased voltage on the other exposure factors, in order to secure greater contrast, is discussed in Experiment 6.

Good contrast can usually be secured on films of the bony skeleton. Occasionally a patient will be encountered whose bones, either from lack of use or age, have undergone considerable atrophy with a decrease in the calcium salts, and on films of which contrast will not be so marked. Because of a similarity in density, contrast will not be so marked on films of soft tissues. The maximum amount of contrast is seldom necessary, especially when the attempt to secure it may diminish detail or other more desirable quality of the films. On films that must be made with a short exposure to prevent blurring from movements, even when using a high milliamperage, it may be necessary to sacrifice contrast to secure detail.

Detail on films is the distinctness with which the finer subdivisions of structures are shown, their margins, edges, contour lines, etc. When detail is good, the cancelli in spongy bone, bone edges, fine markings within the lungs, outlines of the kidneys, or barium-filled portions of the alimentary canal, are shown without haziness and with good definition. Good detail is the most important quality of Roentgen-ray films, and while it is more apparent on films with good contrast, other properties must often be sacrificed to secure it.

There are a number of factors that influence detail. Among these

may be mentioned anode-film distance, immobilization of the part of the body or structures being examined, the contact between film surfaces and intensifying screens, the amount of scattered radiation, and the size of the focal spot of the tube.

Other factors being equal, better detail with the least distortion will be present on films made with the longest anode-film distance; the rays from the focal spot of the tube will be more nearly parallel and will diverge less between the body structures and the film surface.

Movement while an exposure is being made will diminish or destroy detail. Under immobility must be included movements of the body as a whole, movements of a part of the body, the cessation of respiratory motion when films of the thoracic and abdominal viscera are exposed, and movements of the viscera themselves. Rapidity of exposure must be relied upon to secure good detail on films of the stomach with an active peristalsis, and to overcome haziness in the shadows of lung structures from movements transmitted by cardiac contraction. Short exposures often require a high voltage and penetrating rays, which will diminish contrast on films so exposed.

A common cause of lack of detail is poor contact between the emulsion surfaces of films and the fluorescent surfaces of intensifying screens. If contact is imperfect, light originating from a spot, line, or area of the screen will spread over a larger area of film, causing a blurring of the structures on that area (see page 73).

Scattered radiation sometimes will seriously diminish detail and contrast. This can be largely overcome by using a Potter-Bucky diaphragm, and can be decreased by using a small cone or diaphragm and including only a small part of the body on each film.

A small focal spot in a Roentgen-ray tube produces rays that originate from a smaller area than those coming from a larger focal spot, and will, therefore, give films of greater detail. Martin and Holmes found that the same definition was obtained on films with the 10-milliampere radiator tube and the fine, medium, and broad focus universal tubes at anode-film distances of 26 inches, 3 feet, 4 feet, and 5 feet respectively. The 10-milliampere radiator tube will give films of greater detail, when used at the same distance, than any other Coolidge tube. Because of its limited capacity, it can only be used under conditions when longer exposures are permissible. Unless used with this tube, a technique calling for 10 milliamperes will not give better detail than any other kind.

Distortion is the variation from the true size and shape of images of parts of the body when they are projected on to and registered on a film. Since the rays originate from a very small area and spread out in a hemispherical shape which is reduced to a cone by diaphragming, the image of a part of the body on a film is always larger than the part itself. This increase in size is variable. It depends on the distance of the part from the film, on the size of the part, and on the distance of the tube anode from the film. There will be considerable increase in the size of the shadow of a small object some distance from the film, of a large object either removed from or close to the film, while the distortion of a small object near the film is least of all.

Since a long anode-film distance reduces distortion in size to a minimum, the longest practicable distance should always be used. Even images of such a large object as the heart may be obtained with little distortion if the distance is long enough. This is the reason for exposing films of the heart at a distance of 7 feet. Usually, however, the exact size of the images of structures on films is of such little consequence that distortion in size does not detract from the value of the films.

Distortion in shape is perhaps more pronounced than distortion in size. This is especially true if a large film of a large part of the body is made. In the center of the cone the Roentgen-rays will pass directly through the part, producing relatively undistorted images of the structures in their path. From the center of the cone toward the periphery the rays increase in obliquity, because of which the images of structures will be increasingly distorted. The margins or edges of structures near the center of the film will be distorted less than those removed from the center.

Distortion cannot be eliminated, but by careful posing of the patient and placing of the film and tube, it may be kept at a minimum.

From the above discussion of the properties which determine quality, it is apparent that the finest Roentgen-ray films will be of some part of the body that can be immobilized so as to permit of a long exposure, using a tube with a small focal spot, a long anode-film distance or a Potter-Bucky diaphragm, and a cassette with perfect contact between the film and screen surfaces. In actual roentgenographic work there are many circumstances and conditions which make it impossible to attain this ideal. The best that can be done is to select the exposure factors for different regions of

the body that will give the best films under the conditions which exist when such examinations are made.

COMBINATIONS OF EXPOSURE FACTORS.

In exposing films, different conditions require different combinations of factors for different regions of the body, and occasionally require changes in the combinations used for the same region. The combinations of factors given in this chapter are intended for the average Roentgen-ray installation and are sufficiently numerous to meet almost all contingencies that may arise. In the selection of the exposure factors in the various combinations the principles given in Chapter VII for a basic roentgenographic technique have been followed. In all of them as many as possible of the factors have been kept constant, the voltage through the tube being the one most often varied. In the selection of the proper voltage, a thickness-voltage chart (Fig. 40) has been used throughout. Use has also been made of the charts and tables given in Chapter VI showing the operating characteristics of a Roentgen-ray machine and illustrating the laws which govern roentgenographic exposures.

Those given in this chapter do not, by any means, exhaust the possible combinations that may be used with good results. With a basic technique as the foundation, combinations like the ones given, or any others that appear more desirable, may be obtained from it by making one or more of the following changes:

1. Making changes in the anode-film distance to permit of changes in the exposure time.

These are based on the law that the intensity of a Roentgen-ray exposure varies inversely as the square of the distance (Experiment 5). As examples, changing from a 35-inch distance to one of 25 inches reduces the time one-half; from 35 to 22 inches reduces it to 0.4, and to 20 inches to 0.3 of the original time (see Figs. 37 and 38).

2. Increasing the milliamperage in order to reduce the time.

These are based on the law that the intensity of a Roentgen-ray exposure varies directly as the milliamperage (Experiment 4). Possible changes in milliamperage, especially with the 5–100 radiator type tube, are very numerous. The milliamperage may be doubled, reducing the time one-half; it may be increased from 20 to 60 or 80 with corresponding decreases in time; or it may be increased under certain conditions to as much as 100, thus permitting of very short exposures.

3. Increasing the voltage in order to shorten the exposure, and decreasing the voltage to increase the contrast on the films, the latter requiring an increase in exposure time (Fig. 39).

The most important of such changes are the addition or subtraction of 10 peak kilovolts ($\frac{3}{4}$-inch spark gap), the addition most often permitting a reduction in time of one-half, the subtraction requiring a doubling of the exposure time.

Other essentials in a roentgenographic exposure technique, such as the differences in density of the tissues, the absorption of rays by the grid of a Potter-Bucky diaphragm, etc., will be discussed in their proper places.

In the use of this technique it must be emphasized again that there are marked differences in the characteristics and possibly in the thickness-voltage relation for different Roentgen-ray equipments, and that the best results can only be expected when exposures are based on charts and tables and a thickness-voltage chart prepared with the equipment with which they are to be used. In addition to the thickness-voltage chart, the most important of these, and ones that are absolutely essential for satisfactory work, are the tables and charts like those from Experiment 3, showing the manner of obtaining the various secondary voltages with different milliamperages.

EXPOSURE COMBINATIONS FOR FILMS OF THE EXTREMITIES.

Under usual conditions the factors given in the basic technique can be used unmodified for roentgenography of any part of the extremities. This means that by exposing double-coated films with double intensifying screens, using 20 milliamperes for five seconds at a 35-inch anode-film distance with the voltage based on the thickness of the part, roentgenograms of good quality of any part of the extremities will be the result. The part should be measured with a centimeter ruler through its thickest portion and the voltage for that thickness selected from the thickness-voltage chart.

The above technique is based on the assumption that all parts of the extremities of all persons are of exactly the same density, and that variations are only required for differences in thickness. Some differences in density do exist, but they are so slight that a special technique usually is not required. If one wishes to allow for differences in density, in exposing films of parts of elderly people, of parts that have been immobilized for some time, and those of smaller

children, a voltage of 3½ peak kilovolts (¼-inch spark gap) less than that given in the thickness-voltage chart will fulfill all requirements.

Under unusual conditions, as when examining a struggling or crying child, or when, for any reason, immobilization of the part cannot be secured, by using information obtained from the various tables and charts, the time can be so shortened that an interval of quiet sufficient to make an exposure can be caught. The distance may be reduced to 25 inches, thus shortening the time one-half, or to two and a half seconds (Fig. 38). At this distance the milliamperage may be doubled, again reducing the time one-half, or to one and a quarter seconds (Experiment 4). To obtain the same voltage with 40 milliamperes the primary voltage must be increased according to the tables from Experiment 3. If a further reduction in time is necessary, enough additional voltage can be added to the secondary current to decrease the time to 0.2 of its original value or to one-quarter second. ($1.25 \times 0.2 = 0.25$.) The voltage to be added varies somewhat with the thickness of the part and can be determined from Fig. 39.

If the above changes have been correctly made, the resulting films will have the same density as if the basic technique had been followed. The quality will not be quite so good. There will be more distortion and slightly less detail at 25 inches than at the longer distance. There will be less contrast on films made with the higher voltages. Yet for all ordinary purposes, the films will be of good diagnostic quality.

This technique for extremities may be summarized as follows:

Usual technique:

Distance 35 inches
Milliamperes 20
Time five seconds
Voltage appropriate for the thickness from the thickness-voltage chart.

Modifications:

1. Distance 25 inches
   Time two and a half seconds
   Other factors unchanged.

2. Distance 25 inches
   Milliamperes 40
   Time one and a quarter seconds
   Voltage unchanged.

3. Distance 25 inches
   Milliamperes 40
   Time one-quarter second
   Voltage from the chart plus enough to reduce the exposure time to 0.2 of its value (Fig. 39).

EXPOSURE COMBINATIONS FOR FILMS OF THE ABDOMINAL VISCERA.

Because of the likelihood of blurring on films of the abdominal viscera from movements, long exposures through the abdomen are impracticable. Abdominal movements are of two kinds: respiratory motion transmitted from the thorax and motion of the viscera themselves. During the exposure of films, respiration must be temporarily stopped. The absolute cessation of respiration for any length of time is probably rarely accomplished, while it is often difficult to secure even a relative stoppage of respiratory motion. The peristaltic activity of the viscera is, of course, beyond control.

These two types of motion increase the difficulty of roentgenography of the abdominal viscera. An exposure time of five seconds for the kidneys, gall bladder, appendix, and colon, and of one second for the stomach and small intestine are probably the limits for these structures. If the time can be reduced to two and a half or two seconds for the former and a half second for the latter, there will be less likelihood of having the films spoiled by movements.

The density of different parts of the abdomen of the same thickness is not exactly the same, that of the upper portion through the liver, gall-bladder region, and kidneys usually being slightly greater than that of the middle and lower portions. Even in these regions there are probably some individual variations.

As a basis for roentgenographic exposures of the abdominal viscera, a simple modification of the basic technique will suffice. Reducing the distance from 35 to 25 inches will permit a reduction in the time to two and a half seconds, the milliamperage remaining constant at 20, the voltage varied according to the thickness and obtained from the thickness-voltage chart. Doubling the milliamperage will permit a further reduction in the time to one and a quarter seconds. These factors may be used for films of any large part of the abdomen or for a small film of the middle and lower portions. For small films of the liver, gall-bladder region, or kidneys made with a small cone, the greater density usually requires a slight

modification of the technique. An exact rule cannot be given for this, but usually the addition of 3½ peak kilovolts or its equivalent to the voltage or of 5 milliamperes to the current will be sufficient.

To obtain the values of the different factors for a one-second exposure by modifying the basic technique, reference to Fig. 38 will show that 40 milliampere-seconds at a 22-inch distance will give the same intensity as 100 milliampere-seconds at 35 inches. Therefore, films of the abdominal viscera may be taken in one second at 22 inches, using 40 milliamperes with the voltage from the thickness-voltage chart. By increasing the voltage 10 peak kilovolts (¾-inch spark gap) (Fig. 39) and using 40 milliamperes at a 22-inch distance, a set of factors may be obtained for exposures at one-half second for stomachs with an active peristalsis.

These modifications of the basic technique may be summarized as follows:

1. Distance 25 inches
   Milliamperes 20
   Time two and a half seconds
   Voltage appropriate for the thickness from the thickness-voltage chart.

2. Distance 22 inches
   Milliamperes 40
   Time one second
   Voltage from the thickness-voltage chart.

3. Distance 25 inches
   Milliamperes 40
   Time one and a quarter seconds
   Voltage from the thickness-voltage chart.

4. Distance 22 inches
   Milliamperes 40
   Time one-half second
   Voltage appropriate for the thickness from the thickness-voltage chart plus enough to reduce the time one-half (see Fig. 39).

For small areas through the upper part of the abdomen exposed with a small cone, it may be necessary to increase slightly either the voltage or the milliamperage.

EXPOSURE COMBINATIONS FOR FILMS WITH A POTTER-BUCKY DIAPHRAGM.

The absorption of Roentgen-rays by the lead strips of the grid makes necessary a special exposure technique for use with a Potter-Bucky diaphragm. From experiments and practical experience it has been found that this absorption is relatively constant. To compensate for it the intensity of the rays (quantity) must be increased. An increase in the intensity to three times that appropriate for films without the diaphragm is required. Five different kinds of diaphragms made by four manufacturers have been examined and found uniform in this respect. Any modification of the basic technique that will, therefore, compensate for the absorption by the grid will be suitable for use with a Potter-Bucky diaphragm.

The distance to be used with a diaphragm is fixed at 25 inches by the curvature of the grid or, in one with a flat top, by the inclination of the grid strips. Reducing the distance from 35 inches in the basic technique to the required 25 inches, with the other factors the same, will double the intensity of the exposure (Fig. 38). An increase in the milliamperage from 20 to 30 will add another 100 per cent to the intensity, 50 milliampere-seconds at 25 inches being the same as 100 milliampere-seconds at 35 inches. Therefore, for parts of average density, an anode-grid distance of 25 inches, 30 milliamperes for five seconds, with the voltage from the thickness-voltage chart will give uniformly good films with a Potter-Bucky diaphragm.

If it be necessary to shorten the time, as in exposing films of the gall bladder, this may be done by increasing either the milliamperage, the voltage, or both. If the tube permits, the milliamperage may be doubled, thus reducing the time to two and a half seconds; the voltage may be increased 10 peak kilovolts ($\frac{3}{4}$-inch spark gap), permitting a like decrease in time; the milliamperage may be doubled and 10 peak kilovolts added, thus reducing the time to one and a half seconds, or the milliamperage may be doubled and 14 peak kilovolts added, decreasing the time to one second (Fig. 39). If the tube will not permit an increase in milliamperage, voltage increases of 10, 14, and 21 peak kilovolts usually will decrease exposure times to two and a half, two, and one second respectively. An exposure as rapid as one second may give faint grid marks on the film.

Since scattered radiation is largely absorbed, the use of high

voltages with a Potter-Bucky diaphragm is permissible, but contrast will not be so pronounced as when lower voltages are used. There is a limit to the addition of secondary voltage for the purpose of reducing the time of exposures. If the patient is 26 centimeters thick, requiring over 90 peak kilovolts, the voltage is above that which should be used with radiator type tubes and cannot be much increased without exceeding the capacity of even the universal type tubes.

In exposing stereoscopic films with a Potter-Bucky diaphragm with the tube shift across the grid strips, there is more absorption of the rays by the lead strips of the grid than there is if the tube is over the center of the grid, or if the stereoscopic shift is parallel with the strips. This requires an additional modification of the technique. Forty milliamperes instead of 30, or the addition of 5 peak kilovolts to the voltage, will compensate for this increased absorption.

Unless for some special reason, a distance of 25 inches should always be used with a Potter-Bucky diaphragm. A longer distance, 30 or 35 inches, has been suggested for films of the skull and for large films of the abdomen and pelvis. The longer distance reduces distortion, which is increased over that of ordinary films by the separation of patient and films. With longer distances the lateral rays do not pass directly through the openings in the grid so that more of them are absorbed. This may be an advantage in exposing films of parts in which the center is thicker than the margins. To prevent overblackening of the images of the iliac crests, the greater trochanters of the femora, and the flanks, a 36-inch distance for large films of the abdomen and pelvis has been especially recommended by Lawrence.

If a 30- or 35-inch distance is used, the time may be increased to seven and a half and ten seconds respectively (Fig. 37), the other factors remaining the same as for the 25-inch distance. If a five-second exposure at either 30 or 35 inches is to be made, the increase in distance may be compensated for by increasing the voltage. From Fig. 39 it is found that increasing the voltage approximately 7 peak kilovolts or $\frac{1}{2}$-inch spark gap will reduce the exposure time from seven and a half to about five seconds, and that increasing the voltage 10 peak kilovolts or about $\frac{3}{4}$-inch spark gap will reduce a ten-second exposure to five seconds. In each instance the additional voltage is added to that selected from the thickness-voltage chart as appropriate for the thickness of the part being examined.

Thicknesses greater than those permitted by the thickness-voltage

chart are encountered in lateral exposures of the abdomen, the lumbar spine, and the lumbosacral region. In selecting factors for such exposures, using a Potter-Bucky diaphragm, a different type of technique must be used. The basis of this may be a relatively low milliamperage, a relatively long anode-film distance to reduce distortion, a high voltage, but one that can be used with radiator

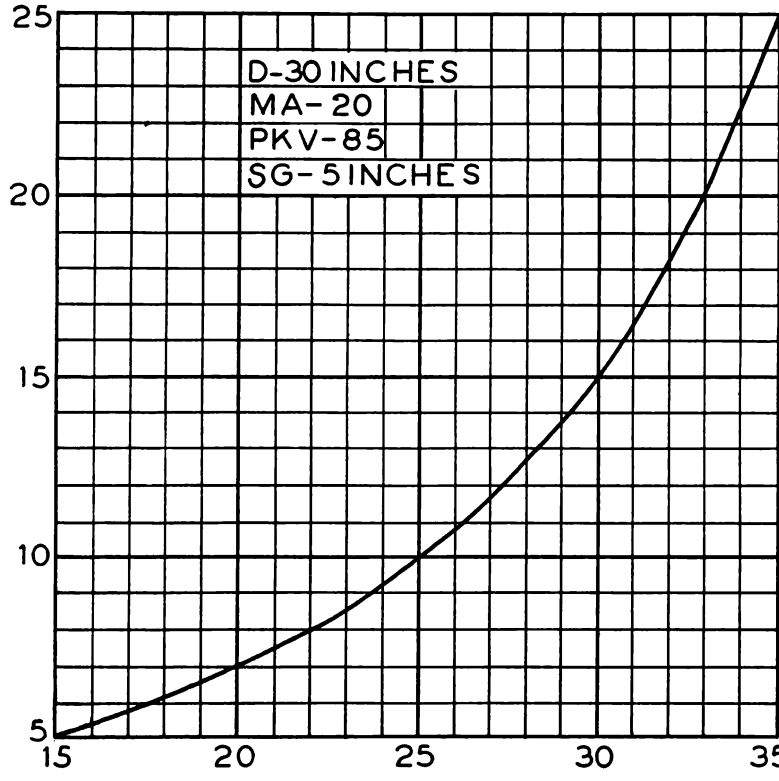

FIG. 45.—An exposure chart for lateral films of the abdomen and lumbar spine, with a Potter-Bucky diaphragm. The ordinates are exposure time in seconds; the abscissæ are thickness in centimeters. The constant factors are given on the chart.

type tubes, and a variation in the time of the exposure depending on the thickness of the part. A technique such as this is graphically shown in the chart in Fig. 45. This is based on 20 milliamperes, a 30-inch distance, and a 5-inch spark gap (85 peak kilovolts). Thicknesses in centimeters are given as the abscissæ and the exposure time in seconds as the ordinates. This chart will be found

suitable for machines with which the thickness-voltage chart can be used and is subject to the same limitations.

This technique for use with the Potter-Bucky diaphragm may be summarized as follows:

For films at a 25-inch distance:
Milliamperes 30
Time five seconds
Voltage from the thickness-voltage chart.

To reduce the time to two and a half seconds,
Use 60 milliamperes or add 10 peak kilovolts
($\frac{3}{4}$-inch spark gap).

To reduce the time to two seconds,
Use 30 milliamperes and add 14 peak kilovolts
(1-inch spark gap).

To reduce the time to one and a quarter seconds,
Use 60 milliamperes and increase the voltage
10 peak kilovolts ($\frac{3}{4}$-inch spark gap).

To reduce the time to one second,
Use 60 milliamperes and add 14 peak kilovolts
($\frac{3}{4}$-inch spark gap)
or, Use 30 milliamperes and add 21 peak kilovolts
($1\frac{1}{2}$-inch spark gap).

For stereoscopic films with the tube shift across the grid strips:

Milliamperes 40
Distance 25 inches
Time five seconds
Voltage from the thickness-voltage chart
or, Milliamperes 30
Distance 25 inches
Time five seconds
Voltage from the thickness-voltage chart plus 5 peak kilovolts.

For films at a 30-inch distance:
Milliamperes 30
Time seven and a half seconds
Voltage from the thickness-voltage chart
or, Milliamperes 30
Time five seconds
Voltage from the chart plus 7 peak kilovolts
($\frac{1}{2}$-inch spark gap).

For films at a 35-inch distance:
Milliamperes 30
Time ten seconds
Voltage from the thickness-voltage chart
or, Milliamperes 30
Time five seconds
Voltage from the chart plus 10 peak kilovolts
($\frac{3}{4}$-inch spark gap).

For films of the abdomen, the lumbar and lumbosacral regions in the lateral direction:
Milliamperes 20
Distance 30 inches
Voltage 85 peak kilovolts (5-inch spark gap)
Time according to the thickness from chart in Fig. 45.

EXPOSURE COMBINATIONS FOR FILMS OF THE THORAX.

The thorax through the lungs is less dense to Roentgen-rays than any other part of the body of the same thickness. The soft tissues and bone of the thoracic wall are like similar structures elsewhere, but air in the lungs reduces the average density to a marked degree. Exact figures of the proportion of chest wall to lung in the antero-posterior diameter of the thorax could not be found, but measurements made from a series of anatomical cross sections indicate that approximately three-fourths of the thickness in adults is occupied by the lungs.

In addition to the lesser average density, movements must be considered when a roentgenographic technique for the lungs is devised. These are of two kinds: those produced by respiration, and those transmitted to the lungs by cardiac contractions. One who has observed the chest with a fluoroscope can appreciate the extent of these transmitted movements, especially in and around the hilus of the left lung.

In roentgenography of the lungs the diminished density makes it possible to use either less penetrating rays or a smaller quantity of rays, a smaller quantity permitting of a much shorter exposure. It has been found that satisfactory films of the chest of an adult can be made with approximately one-seventh the intensity (quantity) of rays required for a similar thickness in other parts of the body.

To diminish the effects on films of movements of the lungs a rapid exposure is necessary. Other factors being equal, the most rapid

exposure will give the greatest detail on the films. To minimize distortion, the longest practicable anode-film distance should be used.

Very rapid exposures at a long distance require accurate timing devices and powerful apparatus. These are usually only found in the best equipped laboratories. A moderately short exposure at an average distance, while not giving extra fine films, can be made with almost any equipment, and should be the technique used, unless special apparatus is available.

A reduction in the quantity of rays to approximately one-seventh of that given for similar thicknesses in other parts of the body in the basic technique will give good films of the thorax of adults. If the antero-posterior diameter of the thorax be measured with a pelvimeter at the level of the fifth thoracic vertebra and the voltage selected for this thickness from the thickness-voltage chart, an exposure of 30 milliamperes for one-half second at a 35-inch distance will be correct. The measurement should be made during quiet respiration. Films should be exposed at full inspiration, and, while the thickness will be greater than when the measurement was made, the increase in thickness is due to inspired air which does not add to the thoracic density. If the milliamperes be increased to 60 and the primary voltage adjusted so that the correct secondary voltage through the tube will be maintained, the time may be reduced to one-quarter second.

Films at other distances may be taken by simple modifications of the technique given for the 35-inch distance. Provided the voltage as given in the thickness-voltage chart be maintained, 10 milliampere-seconds at 30 inches, 20 milliampere-seconds at 40 inches, 45 milliampere-seconds at 60 inches, and 85 milliampere-seconds at 7 feet will all give good films. The time and the milliamperes may be divided to suit the apparatus.

By using 100 milliamperes through the tube, films of the thorax may be exposed in one-tenth second. Ten milliampere-seconds, or two-thirds of the number for the one-half and one-quarter-second exposures at 35 inches, are used. To the voltage from the thickness-voltage chart must be added $3\frac{1}{2}$ peak kilovolts ($\frac{1}{4}$-inch spark gap) to compensate for the reduction in milliampere-seconds.

An exposure of 100 milliamperes for one-tenth second is permissible with the 30-milliampere radiator tube and any of the universal Coolidge tubes. Because of the danger of damaging the tube, such exposures should not be attempted unless the timer is known to be

accurate. The accuracy of the timer can only be determined by actual testing. In exposures using 100 milliamperes, the 5–100 radiator Coolidge tube and the Kearsley stabilizer are both very useful.

For films of the lungs in either the right or left oblique directions, and for transverse views of the thorax, special sets of exposure factors are required. For the oblique views, the distance, milliamperage, and voltage for the antero-posterior views may be used, the time being increased to twice that for such views. For films in the transverse direction the other factors may be selected as for the antero-posterior exposure and the time multiplied by 4.

Films of the thorax through the lungs are rarely exposed with a Potter-Bucky diaphragm. The only occasions for its use are in some instance of injuries to the ribs and for films of the sternum. For such exposures the factors should be selected for a similar view without the diaphragm and the time multiplied by 3. This increase in time will compensate for the absorption of rays by the lead strips of the grid of the diaphragm.

In the exposure of films of the lungs the sets of factors given are based on the density of normal lung tissues or of that containing relatively little pathological material. In case of extensive involvement and the character of the involvement is desired, either the milliamperage, time, or voltage must be increased. This increase depends on the amount of involvement and cannot be accurately stated. In such instances the normal lung tissue will be overexposed.

THE THORACES OF CHILDREN.

The thoraces of adults of different thicknesses are of approximately the same roentgenographic density. If a given thickness of the thorax of a child, however, is compared to a similar thickness of the thorax of an adult, the average density to Roentgen-rays of that of the child is considerably greater than that of the adult. This is most marked in infants and gradually decreases as age advances. Scammon found that at birth lung weight and lung volume are approximately equal, at six months the lung volume is approximately 50 per cent greater than lung weight, and by one year it is almost twice as great. This indicates that as a child grows older the proportion of air to solid tissue in the lungs undergoes a marked increase. This change probably continues for some time after the

first year. It explains the relatively greater opacity to Roentgen-rays of the thoraces of infants and younger children.

This greater opacity makes necessary a special exposure technique for films of the thorax of infants and children, and its decrease as age advances makes impossible the establishment of a rule, based on thickness, for the exposure of such films. Experience leads to the belief that the increase in the thickness of the thorax as age advances is offset by the increase in the relative amount of air in the lungs. In a young child, when respiration cannot be suspended, the time of the exposure should not be longer than one-tenth second. At a 35-inch distance there is little need for varying the exposure factors for infants and younger children. Sixty-five peak kilovolts or a $3\frac{3}{4}$-inch spark gap with 10 milliampere-seconds, irrespective of the age or size up to twelve or fourteen years of age, and an antero-posterior thoracic diameter of approximately 16 centimeters, will give films of good diagnostic quality. Above these limits the technique as for adults should be used.

The exposure technique for films of the thorax through the lungs may be summarized as follows:

For postero-anterior or antero-posterior views of the lungs of adults, voltage appropriate for the thickness as determined from the thickness-voltage chart.

At a 30-inch distance, 20 milliamperes for one-half second, or 40 milliamperes for one-quarter second.

At a 35-inch distance, 30 milliamperes for one-half second, or 60 milliamperes for one-quarter second.

At a 40-inch distance, 40 milliamperes for one-half second.

At a 60-inch distance, 45 milliamperes for one second.

At an 84-inch distance, 42.5 milliamperes for two seconds.

Using 10 milliampere-seconds (100 milliamperes for one-tenth second):

Distance 35 inches.
Voltage from the thickness-voltage chart plus $3\frac{1}{2}$ peak kilovolts ($\frac{1}{4}$-inch spark gap).

For oblique views through the thorax, factors as for the antero-posterior views, except that the time is doubled.

For transverse views through the thorax, factors as for the antero-posterior views, except that the time is quadrupled.

For films of the thorax with a Potter-Bucky diaphragm, select the factors for a similar view without the diaphragm and multiply the time of the exposure by 3.

For the lungs of infants and younger children:
Distance 35 inches
Voltage 65 peak kilovolts or $3\frac{3}{4}$-inch spark gap
Milliampere-seconds 10.

EXPOSURE COMBINATIONS FOR FILMS OF THE HEAD.

The density to Roentgen-rays of parts of the head, especially through the skull, is not only greater, but it also varies more at different ages than that of any other part of the body. There may be at least two causes for the relatively greater density. One of these may be the bone of the skull. In either the antero-posterior or lateral direction, Roentgen-rays must pass through four layers of compact bone, the inner and outer tables of the skull on both sides. In examining dried skulls some will be found with relatively thin bone; in others the bone is much thicker. In none does it appear to be so thick nor so dense as in the shafts of some of the long bones, the femur for example.

The marked differences in the thickness of the bone of different skulls do not produce as much difference in the density to Roentgen-rays as one would expect, and the fact that the total thickness is less than that of other bones leads to the belief that there may be another and more important cause for average head density. This may be due to the presence of the cerebrospinal fluid, to the large quantity of blood in the cerebral vessels, or to some cause within the brain itself.

Variations in the density of the tissues of the head at different ages are quite marked. The density is least in infancy and early childhood, gradually increases as age advances, is at its maximum during adult life, and probably slightly decreases during old age. This variable density due to age is probably caused by differences in the calcium content of the bones of the skull.

The variations in the density of parts of the head control the selection of exposure factors for films through this region. While the density is least in infancy and early childhood and gradually

increases, it has been found that the latitude in Roentgen-ray films permits of the use of a few combinations of exposure factors for roentgenography of the head. Selecting a voltage based on the thickness from the thickness-voltage chart, the required intensity of the rays will need to be varied from one that is equal to that given in the basic technique to one that is three times as great.

For the head of infants and young children in the lateral or transverse direction, the intensity should be equal to that given in the basic technique; in the antero-posterior direction the intensity should be 50 per cent greater. For the head of older children in the transverse direction, the intensity should be twice that of the basic technique, and for films in the antero-posterior direction it should be two and a half times as great. For films of the head of adults in the transverse direction the intensity should be from two to two and a half times, and in the antero-posterior direction it should be three times that given in the basic technique. For films of the skull of feeble, elderly persons, it should be about the same as that for older children.

Taking the voltage according to the thickness as given in the thickness-voltage chart and the different intensities of rays required by different ages, it is relatively easy to devise sets of exposure factors suitable for roentgenography of the head. Since many views through the head are made neither in the direct antero-posterior, postero-anterior, or lateral directions, as in nasal accessory sinus, jaw, and mastoid films, in selecting the voltage it is especially important that the measurements of the thickness be in the line that will be traversed by the central rays from the tube and of the thickest portion through which the rays must pass. Such measurements can be made more accurately with a pelvimeter than with a ruler.

Using a constant distance of 25 inches, the different intensities may be obtained by varying the time of the exposure and the milliamperage. Twenty milliamperes for two and a half seconds will give the same intensity as the factors in the basic technique; 30 milliamperes for two and a half seconds will give an intensity 50 per cent greater; 20 milliamperes for five seconds an intensity twice, 25 milliamperes for five seconds will give one two and a half times, and 30 milliamperes for five seconds will give an intensity three times that of the basic technique. It should be understood that any combinations of milliamperage and time that will give the same number of milliampere-seconds will give the same intensity as long as the secondary voltage is kept constant.

For films of the head exposed with a Potter-Bucky diaphragm, the separation of the head and cassette by the top and grid, materially increases distortion in size. To decrease this, films of the head with the diaphragm are better if exposed at a distance of 30 instead of 25 inches. To compensate for absorption by the grid and the increased distance, 10 to 14 peak kilovolts must be added to the voltage selected to give the correct exposure.

The proper groups of exposure factors as indicated in the preceding paragraphs may be summarized as follows:

1. For lateral or transverse views of the head of an infant or young child:
   Distance 25 inches
   Milliamperes 20
   Time two and a half seconds
   Voltage from the thickness-voltage chart.

2. For postero-anterior or antero-posterior views of the head of an infant or young child:
   Distance 25 inches
   Milliamperes 30
   Time two and a half seconds
   Voltage from the thickness-voltage chart.

3. For lateral or transverse views of the head of an older child:
   Distance 25 inches
   Milliamperes 20
   Time five seconds
   Voltage from the thickness-voltage chart.

4. For postero-anterior or antero-posterior views of the head of an older child:
   Distance 25 inches
   Milliamperes 25
   Time five seconds
   Voltage from the thickness-voltage chart.

5. For lateral views of the head of an adult:
   Distance 25 inches
   Milliamperes 20 to 25
   Time five seconds
   Voltage from the thickness-voltage chart.

6. For antero-posterior or postero-anterior views of the head of an adult:
   Distance 25 inches
   Milliamperes 30
   Time five seconds
   Voltage from the thickness-voltage chart.

7. For the exposure of films with a Potter-Bucky diaphragm use a 30-inch distance, the milliamperage and time for the view and age as given above, select the voltage appropriate for the thickness from the thickness-voltage chart and add 10 to 14 peak kilovolts ($\frac{3}{4}$- to 1-inch spark gap).

The exposure combinations given in this chapter have been more or less arbitrarily grouped under five headings. This is not intended to indicate that the combinations given in each group should only be used for exposures of films of parts of the body for which that group was primarily designed. The combinations in the first group, those for the extremities, may be used for any parts of the body that are of average density (see page 120). These include the extremities, the shoulders and hips, the neck, and the abdomen. Similarly those combinations for films of the abdominal viscera also may be used for the same parts as those of the first group. The two groups of factors for parts of the same relative density have been included because the greater anode-film distance and longer exposure time used for the extremities will give better films than the shorter distance and time suggested for films of the abdominal viscera, where the immobilization is uncertain.

In exposing films of the abdominal viscera with a Potter-Bucky diaphragm, as the kidneys and gall bladder for example, the factors would be selected from those for use with the diaphragm and not from those for the abdominal viscera. The exposure combinations for the thorax through the lungs are intended primarily for films of the lungs, but they serve as well for films of the ribs above the diaphragm and for those portions of the mediastinum the delineation of which depends on the contiguity of the air-filled lungs. Oblique and lateral views of the sternum and thoracic vertebræ take the same exposure factors as similar views of the lungs, but the ribs below the diaphragm and antero-posterior views of the thoracic vertebræ require the same combinations as films of the abdomen, either with or without a Potter-Bucky diaphragm. Exposures of the mandible take the same combinations as do those of other parts of the head.

The different groups include more than forty combinations of exposure factors. Familiarity with all of them is not necessary for satisfactory roentgenographic work. A few, probably less than one-fourth, will be practically all that are required, even in a busy Roentgen-ray laboratory. The beginner especially is cautioned to work with as few of them as possible. One combination for films of the extremities, one combination for films of the abdominal viscera without a Potter-Bucky diaphragm, except the stomach, and one for the stomach, one or two for films with a Potter-Bucky diaphragm, one for films of the lungs of an adult, and one for films of the lungs of infants and children, and those for films of the head will fulfill almost all requirements.

If dependence is placed on a suitable thickness-voltage chart for the selection of the proper voltage, remembering the distances, milliamperages, and exposure times for so few combinations will be easy. In becoming conversant with these combinations, it may be advisable to copy them on a piece of paper and post them, with the thickness-voltage and other charts and tables, near the control panel of the Roentgen-ray machine with which they are to be used. By so doing they may be referred to quickly at any time. Then, as experience increases, other combinations may be added, which will give a greater latitude in the selection of factors for different roentgenographic exposures.

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CHAPTER X.

ROENTGENOGRAPHIC TECHNIQUE WITH THE UNIT TYPE ROENTGEN-RAY MACHINE.

In the unit type are included all those Roentgen-ray machines which do not have a motor-driven or valve-tube rectifier, but which depend on the radiator type Coolidge tube for the rectification of the secondary current. These are neither as complicated nor as expensive as the larger type. This probably accounts for the larger number of different models of this type that have been made and sold to physicians and dentists. These different models make it impossible to devise a technique that is applicable to all of them. The differences between the two types, an explanation of the operating characteristics of unit type machines, a discussion of the kind of roentgenographic technique that is required with them, and especially the delineation of a method of developing such a technique are all that can be included. Since much that is applicable to all roentgenography, given in Chapters VI, VII, VIII, and IX cannot be repeated, these should be studied as an introduction to this chapter.

The chief differences between the interrupterless and the unit types of Roentgen-ray machines are in the smaller size and capacity of the latter, and the fact that the unit type is not equipped with a spark gap or other instrument for directly measuring the voltage of the secondary circuit. The capacity of machines of the unit type is limited by that of the radiator type Coolidge tubes used with them. This is 10 milliamperes at not more than a 5-inch gap with the 10-milliampere radiator tube, 30 milliamperes at not more than a 5-inch gap with the 30-milliampere radiator tube, and 10 milliamperes at a 3-inch gap with the right angle and oil immersed dental tubes.

With these machines the voltage of the inverse current (the suppressed half of the high-voltage waves) is higher than that of the half-waves that pass through the tube. This makes impossible the testing of the voltage through the tube by means of a spark gap of any kind. To compensate for this, quite often the primary volt-

meter is calibrated by the manufacturer so that a certain voltmeter reading will give a definite kilovoltage or spark gap through the tube. Even when this information is furnished with the machine, it is advisable to depend more on tests of the photographic effect of different machine settings than on the calibrations.

Some unit type Roentgen-ray machines are not provided with a voltage control in the primary circuit, there being but one secondary voltage available for use. If a voltage control is provided, it is usually a small autotransformer. These have different steps in different models. A common form has 3 voltage steps, those which presumably give a voltage equivalent to a 3-, 4-, and 5-inch spark gap in the secondary circuit and a small autotransformer with 10 steps of 2 to 4 volts each to adjust the voltage. Other forms of autotransformers are also supplied. Machines of more recent manufacture have as many as 14 to 20 steps in the autotransformer, giving intervals of $\frac{1}{4}$-inch spark gap or less in the secondary circuit. This is about the same as the more common arrangement in the larger machines.

Each unit type machine is provided with an alternating current voltmeter in the primary circuit. This either measures the voltage of the current passing into the autotransformer or that passing from the autotransformer to the step-up transformer. The second is the more common form. The voltmeter has about the same use as in larger machines. It serves as the only indicator of the voltage of the secondary current, and therefore, as the only indicator of the quality of the resultant rays. All calibrations of this type of machine either in terms of secondary voltage or in terms of the photographic effect of different machine settings, must be made in voltmeter readings.

In roentgenographic work with a unit type machine the laws which govern roentgenographic exposures, as explained in Experiments 4, 5, and 6, Chapter VI, are usually applicable. With the other factors constant, the photographic effect of different exposures varies directly as the milliamperage of the current through the tube, and directly as the times of the exposures. With the other factors constant, the intensity of an exposure varies inversely as the square of the anode-film distance. The charts showing modifications of exposures necessary for changes in distance (Fig. 37 and 38) may be used with unit type machines. However, the chart showing changes in exposures necessary with changes in the voltage of the secondary current (Fig. 39) is not always applicable. Since the technique

developed with the unit type machine may include all possible voltage and milliamperage variations, the use of a chart for this purpose is unnecessary.

The operating characteristics of the unit type machine are much the same as those of larger machines. For instance, with a particular milliamperage, a certain voltmeter reading and control setting in the primary circuit will give a constant kilovoltage through the tube. If the milliamperage is changed the voltage will either rise or fall, depending on whether the milliamperage is increased or decreased. To keep the secondary voltage constant with a change in milliamperage, the primary voltage must be changed by the autotransformer before the exposure begins, so that the voltmeter readings during the exposures will be the same.

TABLE XV.

Spark gap.	Milliamperes.		
	10.	20.	30.
3	120	127	140
4	123	127	140
5	125	132	140

TABLE XV.—This table shows the voltmeter readings on a unit type machine that are required with each of the three voltage steps, with the three milliamperages, to give a constant voltage through the tube during the exposures.

This is illustrated in Table XV. The voltmeter readings were obtained from the same machine used in making the chart shown in Fig. 46. That the secondary voltages may be constant at the different milliamperages with each of the three spark-gap settings, on this machine the voltmeter must read 115 volts during the exposures. Meter readings before the exposures begin, for the different milliamperages, are not the same. For example, with the setting for the 3-inch gap, with 10 milliamperes, the reading is 120 volts; with 20 milliamperes, it is 127 volts, and with 30 milliamperes, it is 140 volts. If this precaution is not observed, changing the milliamperage will give different secondary voltages, producing rays of different penetrability, requiring a change in the time of the exposures. Under such circumstances, since the voltage is not constant, the law that the photographic effect varies directly as the time of the exposure and as the milliamperage will not apply.

In developing a technique for use with the unit type of Roentgen-ray machine, the principles with reference to the development of a basic technique as given in Chapter VII should be followed, modified to meet the limitations of this type machine. The selection of the exposure factor to be most often varied depends on the number of voltage steps in the autotransformer. With machines having 14 to

20 steps, thus giving a sufficient number of secondary voltages, the voltage may be made the chief variable factor and a thickness-voltage chart prepared (Chapter VIII). For those giving secondary voltage selections greater than ¼-inch spark gap or its equivalent,

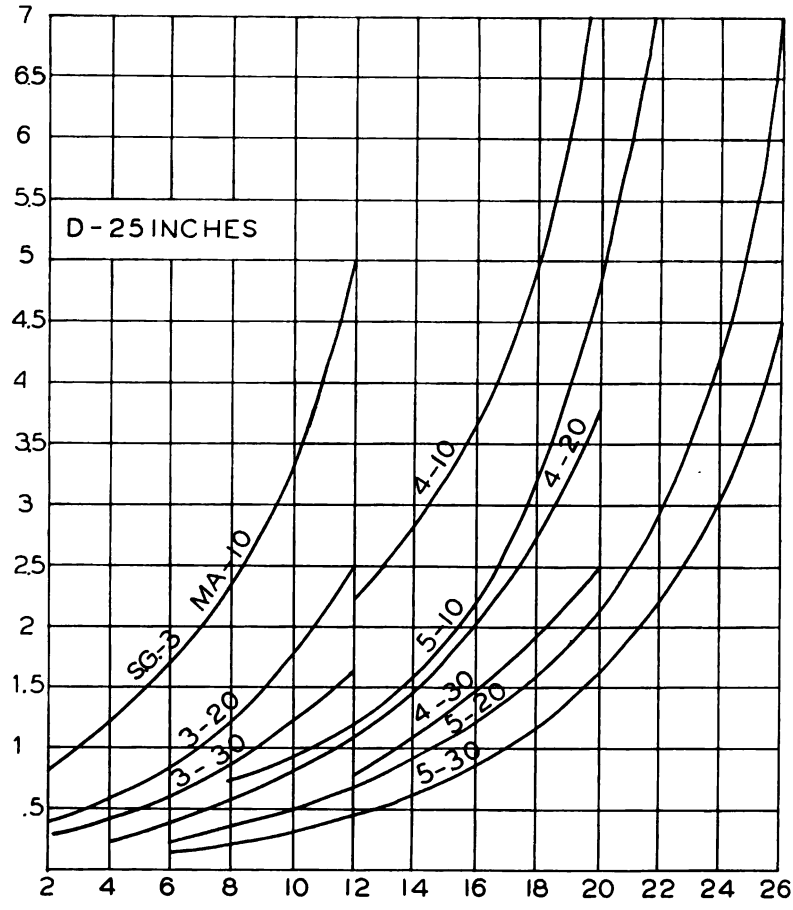

FIG. 46.—Exposure chart for a unit type machine having three voltage steps. The abscissæ are thicknesses in centimeters; the ordinates are exposure time in seconds; the voltage and milliamperage are given on the lines of the chart; the anode-film distance is 25 inches.

especially those types with three voltages, the time of the exposure must be the chief variable factor. For those with a single voltage, that corresponding to a 5-inch spark gap, it may be necessary to vary both the time of the exposure and the anode-film distance.

An exposure chart, answering the same purpose as the thickness-

voltage chart for larger machines, and from which the sets of exposure factors may be accurately selected before an exposure begins, can be made for the unit type. In all such charts the different thicknesses of the parts of the body to be examined should be the basis for the different groups of exposure factors. A chart of this kind, made for a unit type machine with three voltage selections, is shown in Fig. 46 (compare with Fig. 41).

In this chart the ordinates are the time of the exposures in seconds; the abscissæ are thicknesses of tissue in centimeters. The chart was made with a constant 25-inch anode-film distance. To give as much adaptability as possible to the selection of appropriate sets of exposure factors for different thicknesses, three milliamperages—10, 20, and 30—are included with each of the three voltage selections. From one to as many as nine different combinations of voltage, milliamperage, and time are given on this chart for each thickness, each combination giving films of approximately the same density.

An exposure chart can be made for any model of unit type machine. A somewhat different kind would be required for each model. For example, for a machine equipped with a 10-milliampere radiator tube with three voltages, the chart could be similar to the one in Fig. 46, omitting the lines for 20 and 30 milliamperes. For one with a 5-inch spark gap as the only secondary voltage, a longer distance would need to be used for the thinner parts, but the three milliamperages could be retained. For a machine with more than three voltages, the voltage could be made the variable factor within the voltage limits and either above or below these limits, as necessary, the time could be changed, using the 5-inch gap for the greater thicknesses with an increasing exposure time, and the lowest voltage for the lesser thicknesses with a decreasing time. Only a little ingenuity should be required to devise a chart suited to the peculiarities of any other model of the unit type.

There is no way of devising a chart or perfecting a particular form of technique that is applicable to even a major portion of unit type machines, as can be done for the interrupterless form. Neither can exposure factors known to give good films on a large machine always be used with good results on the unit type. Although the statement is made that the roentgenographic results are the same with similar exposure factors on the two types of machines, this has not always been found to be correct. By comparing the thickness-voltage chart (Fig. 40) with Fig. 46, the possible differences can be seen. Reducing the 35-inch distance of the former to the 25-inch distance of the

latter will reduce the number of milliampere-seconds to 50. This quantity on the small machine with the 5-inch gap is suitable for a thickness of 20 centimeters, while on a large machine with a 5-inch gap the appropriate thickness is 24 centimeters. For similar exposures with the lower voltages, the difference in thicknesses of tissue is not quite so marked.

The improbability of one being able satisfactorily to transfer a set of known exposure factors for an interrupterless type machine to one of the unit type, or of using with success a chart on one unit type machine that was devised for another, requires that a chart be made for each unit type machine. The only way that this can be done quickly and satisfactorily is by means of experimental exposures through paraffin blocks. It is not even possible to outline a set of experiments for this purpose, as was done in Chapter VIII for the thickness-voltage chart. With a set of paraffin blocks, one must depend on one's own ingenuity in planning and performing the experiments, in selecting the constant and variable exposure factors, and in working out the chart for use with the machine. The experience gained by so doing will more than compensate for the expense, the time, and the effort required.

When a chart has once been perfected, by making changes in the different exposure factors according to the laws governing roentgenographic exposures, and making the changes known to be required for films of the thorax, for films of the skull, and for exposing films with a Potter-Bucky diaphragm, all other required exposure technique possible with the unit type can be derived from it. To illustrate the ways in which this may be done, the sets of exposure factors for different regions of the body indicated in the following discussion, based on the chart in Fig. 46, are included as examples.

For films of any part of the extremities, the factors appropriate for the thickness as taken directly from the chart may be used. When immobilization can be secured, it is preferable to use the lowest voltage with the longest exposure time. This will give films of maximum contrast. The chart gives nine different combinations of time, milliamperage, and voltage that may be used for a part 12 centimeters thick. The best films would be obtained with one of those using the 3-inch gap, higher voltages and shorter exposure times being used only when immobilization is uncertain.

Except the stomach, for films of parts of the gastrointestinal tract within the abdomen, exposures should usually not be longer than two and a half seconds; occasionally, however, exposures as

long as five seconds are permissible. A film of an abdomen of a thickness of 22 centimeters or less may be made in two and a half seconds by selecting the appropriate factors from the chart. A five-second exposure time may be used for the other abdominal structures.

Peristaltic motion of the stomach will usually blur films that are made with an exposure time of more than one second. For this reason, with the machine used in making this chart, if the patient's abdomen is more than 17 centimeters thick, stomach films at a 25-inch distance cannot be made satisfactorily. By decreasing the distance to 20 inches the time may be reduced one-third (Fig. 38), thus permitting films of the abdomen up to 20 centimeters in thickness to be made within the one-second limit. With this particular machine, it is impracticable to attempt to make films of the stomach in an abdomen that is more than 20 centimeters thick. This is the chief objection to the unit type as a general purpose roentgenographic machine.

The absorption of Roentgen-rays by the lead strips of the grid of a Potter-Bucky diaphragm increases considerably the quantity of rays required for satisfactory films. Experience leads to the belief that absorption by grids of different models is about the same. With the other factors constant, the absorption of the grid of a diaphragm requires that the exposure time, selected from the chart as appropriate for the thickness of the part, be multiplied by 3 to give films of good quality. If this should not be found correct, it will be necessary to experiment with actual exposures, either with patients or through paraffin blocks, to determine the correct modification.

With the same voltage and distance, films of the thoraces of adults require approximately one-seventh of the quantity of rays necessary for other parts of the body of the same thickness. Such films should be made with the longest practicable anode-film distance. With the unit type machine this should be 30 or 35 inches. To determine the time and milliamperage for films of the thorax at a 30-inch distance, multiply the number of milliampere-seconds for the same thickness obtained from the chart by 1.5, and divide by 7. For films at a 35-inch distance, multiply the number of milliampere-seconds required for that thickness as determined from the chart by 2, and divide by 7. The multiplication is required because of the change in distance (Fig. 37), and the division by 7 because films

of the thorax require one-seventh the quantity appropriate for the same thickness of another part of the body.

For example, from Fig. 46 it is found that, using a 4-inch spark gap and 30 milliamperes, the time required for 20 centimeters thickness is two and a half seconds, or 75 milliampere-seconds. Multiplying 75 by 2 gives 150; dividing by 7 gives approximately 21 as the number of milliampere-seconds (21 milliamperes for one second) to be used in exposing a film of a thorax that is 20 centimeters thick, using a 4-inch spark gap, at a 35-inch distance. The voltage through the tube must not be changed. This means that when using 21 milliamperes during the chest exposure, the voltmeter should read the same as during the 30-milliampere exposures used in making the chart. By using this rule, a reference table can easily be made that will give the number of milliampere-seconds for thoraces of different thicknesses, at different voltages, at any distance.

It must be remembered that films of the thoraces of infants and young children, for reasons given on page 153, require a proportionately greater voltage or a longer exposure time than do those of adults. Since the exposure factors for this purpose are relatively constant, irrespective of the size or age of the infant or child, when by trial exposures they have been once determined, they may be used for each succeeding similar examination.

The variations in the density for Roentgen-rays of parts of the head requires a special exposure technique for films of this region (see page 155). Using a voltage based on the thickness and obtained from an exposure chart like Fig. 46, for satisfactory films the intensity must be increased from one to three times. With unit type machines, this can best be secured by appropriate increases in the exposure time. The required changes are as follows: (1) For lateral views of the head of infants and young children an increase is not necessary; for antero-posterior views the time should be increased one-half. (2) For transverse views of the head of older children the time should be doubled; for antero-posterior views the time should be increased two and a half times. (3) For transverse views of the head of adults the time should be increased from two to two and a half times; for antero-posterior views it should be increased three times. (4) For films of the head of elderly persons the increase should be about the same as that for older children. In measuring the thickness to select the voltage, precautions given on page 156 should be observed.

CHAPTER XI.

MISCELLANEOUS INSTRUCTIONS.

In selecting the size of film to use, in posing patients, and in making Roentgen-ray exposures there are many general precautions that should be observed. For convenience these are grouped together and included in this chapter.

SIZE OF FILMS.

The film used for any Roentgen-ray examination should be large enough adequately to include the region to be examined, but, for the sake of economy in materials, it should not be much larger. The size of the part being examined and the exactness with which the pathology can be located should control the size of the film. For example, a Colles' fracture can be so definitely located that a $6\frac{1}{2}$- by $8\frac{1}{2}$-inch film is large enough for making two views of the injury. On the other hand injuries of the pelvis can rarely be definitely located either by the patient or the examiner; they are apt to be multiple and widely separated so that films should include the entire pelvis and the upper ends of both femora.

In selecting a film to be used for any purpose, ample allowance must be made for distortion in size. For small parts close to the surface of a cassette this is not marked, but for large parts, especially if removed from the surface of the cassette, the increase in the size of the image is considerable. Also it increases with the size of the part being examined and the size of the film and is most marked on films exposed with a Potter-Bucky diaphragm. For large parts, such as a thick shoulder or hip, in order to be certain that the whole part will be on the film, the margin of film projecting beyond the part should be quite liberal, about 2 inches without and 3 inches with a Potter-Bucky diaphragm.

When using films in cassettes, allowance must be made for the projection of the surface of the cassette beyond the margins of the film. This varies with the kind of cassette being used. On some it amounts to $\frac{3}{8}$ inch; on others it is as much as $\frac{3}{4}$ inch. It is a good

practice to make scratch marks on the face of all cassettes, parallel with the sides and ends, and exactly over the margins of the film (Fig. 47). If this is done, the exact film size is shown on the face of the cassette and allowance can be made for the difference in size between the film and its container.

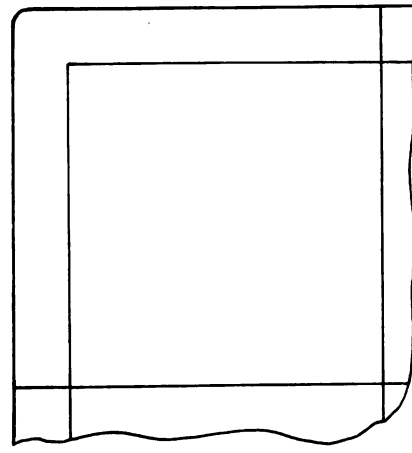

FIG. 47.—Scratch marks on the surface of a cassette over the margins of the film and dividing the film into halves both longitudinally and transversely.

POSITION OF THE IMAGE ON THE FILM.

Even if the roentgenographic quality of films be good, their appearance can be seriously impaired by the position of the images on them. If an image extends obliquely so that a film must be placed on one corner in order to examine it, that film is not as satisfactory nor can it be examined as easily as one in which the chief lines of the images are parallel with the film margins. Long bones should be shown with their long axes parallel either with the sides or ends of the film; parts of the trunk should have the sagittal plane, the vertebral column, or the side of the trunk, parallel with the film margins; the basal part of the skull should be parallel with the side of the film; even an image of the foot should have either the mesial margin or the sole parallel with one side or end of the film. Observing this precaution is essential if the best appearing films are to be produced.

NUMBER OF EXPOSURES.

The number of exposures that should be made in any Roentgen-ray examination varies with the region and the nature of the condi-

tion being studied. Enough should be made to show adequately, usually in different projections, the structures in question. Holmes and Ruggles say that "A roentgenogram showing only one view is an isolated observation, and is to be relied upon less, perhaps, than a single observation in any other branch of medicine." This statement probably is exaggerated for emphasis, yet in many instances it is literally true.

Especially in making an examination of a part to detect bone injury or disease, at least two exposures, as nearly as possible at right angles to each other, should always be made. One who has examined many roentgenograms of fractured long bones is familiar with the fact that fragments appearing to be in perfect position on one view may be shown to be widely separated on a view made at right angles to the first and that occasionally a fracture is seen on one view and not on the other. These two views can be made on one film if it is large enough by covering half the cassette with a piece of lead or lead rubber while the other half is exposed. To aid in making such exposures, scratch marks on the surface of the cassettes, accurately dividing them into equal parts both longitudinally and transversely, will be found helpful (Fig. 47).

In securing two views of an injured extremity it is usually possible to turn the part through the required angle of 90 degrees. Occasionally, as in case of a fracture of the shaft of the femur, turning the part is not practicable. It is then advisable to turn the tube so that the rays are directed horizontally through the part on to a cassette that is standing on edge. The covering material protecting one-half of a film exposed in this manner may need to be fastened to the cassette with strips of adhesive plaster.

Should a joint be flexed and the examiner not be able to straighten it, a lateral view of the joint and the bones both above and below the joint may be taken. For views at right angles to the lateral view it may be necessary to make two exposures, one of the bone above the joint, and the other of the bone below the joint. Small films or one-half of a medium-sized film may be used for each of these exposures. Considerable manipulation and ingenuity may be required, such as supporting the extremity and cassette at an angle with sand bags or pillows, and tilting the tube at quite an angle, to obtain the required views of the entire injured region at right angles to each other. An examination cannot be considered complete until this has been done.

In making examinations of injured parts when views at right

angles to each other are difficult or impossible to secure, as of the shoulder or hip, stereoscopic films should always be taken. Stereoscopic films should always be made of injuries to the pelvis and of suspected injuries of the vertebral column. Even when it is possible to make a lateral view of the vertebral column, the superimposed images of the small parts of the vertebræ require stereoscopic films for a careful examination.

Case emphasizes the necessity of a constant technique in roentgenography of bone and joint lesions and describes the positions and views that should be made routinely of different bones and joints of the body. The number of views required for the complete examination of each part of the body is given in the detailed description of roentgenography of the different regions in following chapters.

DIAPHRAGMING.

By diaphragming is meant the use of cones, or of openings of various sizes in pieces of lead or lead rubber, to limit the rays that strike a part being exposed so that the beam is not much larger than the film that is used. Proper diaphragming reduces scattered radiation to a minimum, thus giving films of maximum detail and contrast. While it may not be of special importance in exposing films of thin parts with a relatively low voltage, diaphragming is of the greatest importance in making exposures of thick parts without the use of a Potter-Bucky diaphragm.

It is good practice never to use a beam of Roentgen-rays that is much larger than the size of the film being exposed. The size of the beam can be controlled and directed by using cones of various sizes. The area of film that will be covered by each cone in the equipment at the different distances it is used may be determined by measuring the diameter of the area on the table illuminated by the filament when the filter under the tube has been removed. For example, a cone that is $2\frac{1}{2}$ inches in diameter at the small and $3\frac{3}{4}$ inches in diameter at the large end will give an area of 8 inches in diameter at 25 inches distance and one of about $11\frac{1}{2}$ inches diameter at 35 inches. One should be familiar with the area covered at the different distances and use the cone best suited for the work to be done.

If an assortment of cones suitable for all purposes is not available, diaphragming may be done by inserting in the slot under the tube with the filter a piece of lead with an opening of appropriate size in

the center. An assortment of lead diaphragms of this kind suitable for all purposes may be prepared and kept on hand for use.

The same purpose may be served by covering the part to be exposed with a piece of lead or lead rubber with an opening of proper size in the center. If this kind of diaphragm is used, a cone or a diaphragm of lead may be omitted.

Since a Potter-Bucky diaphragm eliminates scattered radiation, diaphragming is not necessary when one is used.

IMMOBILIZATION.

The absolute immobilization of a part of the body during a Roentgen-ray exposure is of the greatest importance. Not only gross movements but a very slight movement, or even a very fine tremor, will impair or destroy detail on a Roentgen-ray film. In exposing films of an extremity it is of the greatest importance to have other parts of the body held quiet as well, for any movement of any portion will be transmitted to the part being examined. To obtain this degree of immobility it is necessary that the patient understand that no movement at all is to be made during the exposure. Requesting the patient to keep all parts of the body still will usually accomplish the desired result.

Even if a patient attempts to coöperate in this particular, it often happens that he either is unable to remain perfectly quiet or his intentness defeats its own purpose. This is especially true of those who are in pain from an injury, or of a young patient. To assist in immobilization of a part during an exposure, a number of devices have been advocated. These include a thin board with a round pin in one end to be grasped by the hand while lateral or transverse views of the wrist or forearm are being made, a long board with a short piece at right angles at one end to which the foot may be fastened during exposures of the ankle, leg, knee, or thigh, and many others.

Perhaps the most useful immobilizing device that has been described, and one that can be used for almost any purpose, consists of two sand bags, each weighing 3 to 5 pounds, connected by a long strip of heavy cloth. The cloth should be 10 to 12 inches in width and long enough to allow each of the sand bags to hang over the edge of the table about 2 feet. The sand bags should be as long as the cloth is wide. A light-weight khaki cloth is suitable both for the sand bags and the connecting strip. The sand bags may be fastened to the strip with small hooks so that they may be detached

while the strip is laundered. For want of a better name a device of this kind may be called a double sand bag or a weighted bandage (see Figs. 60 and 95).

A double sand bag will fill almost all requirements for an immobilizing device in a Roentgen-ray laboratory, except those for which a compression band on a Potter-Bucky diaphragm can be used and for immobilizing the kidneys or other viscera during exposures. It may be used for any part of the extremities, or for any part of the head. When not in use, it may be suspended over one end of the table. A Roentgen-ray laboratory is not quite completely equipped unless it contains at least one double sand bag available for immediate use.

SUSPENSION OF RESPIRATION.

Just as films of an extremity may be blurred by movements, so can films of the abdominal or thoracic viscera be blurred and detail on them destroyed by breathing during the exposures. Respiratory movements will also be transmitted to the head, producing decreased detail on films of the skull, of the mastoid or nasal accessory sinuses, the jaws, or any other portion. To overcome this difficulty, respiration must be suspended during the exposure of films of these regions.

In order to secure the coöperation of the patient in this particular, it is essential that he be carefully instructed as to what he is expected to do. Time spent in doing this so well that there is no doubt in the patient's mind as to what should be done will prevent making many spoiled and worthless films. It is even advisable in many instances to rehearse with the patient before the exposure is made.

If a patient is simply told to "hold your breath," almost invariably a rather deep inspiration will be taken before the breath is held. This suffices for films of any part of the skull, but care should be observed not to begin an exposure until after the inspiratory movement is completed and the period of cessation begins.

Exposures of the lungs should be made at full inspiration. Preparatory to making such exposures the patient should be instructed that he will be asked to take in a deep breath and hold it while the exposure is being made. The instructions to the patient should be about as follows: "I will ask you to take in a deep breath, then hold it, and remain perfectly quiet while I make this exposure." Here, again, the operator must be certain that the inspiratory act has been completed before the exposure is begun.

The cessation of respiratory movements is not nearly so difficult for films of the skull or lungs as it is for films of the abdominal viscera. Slight movement will not affect films of the skull, and exposures of the thorax are usually so short that there is little opportunity for motion, but films of the abdomen are more prolonged so that movements are more likely to occur. For this reason more care is required in instructing the patient when films of abdominal viscera are to be made.

Because the lessened thickness of the abdomen at the end of expiration makes it possible to use a lower voltage through the tube, exposures of abdominal viscera should be made at the end of expiration. There are two methods of proceeding. One, advocated by George and Leonard in exposing films of the gall bladder, is to have the patient breathe quietly until told to hold the breath, which instruction is given at the end of expiration. This is the preferable method when rapid exposures, as those of the stomach, are being made. The other is to instruct the patient to take in one or two deep breaths and then hold the breath at the end of expiration. Each act of this sequence is done at the instruction of the operator. This procedure seems to be the preferable one when longer exposures—from two and a half to five seconds, as when a Potter-Bucky diaphragm is used—are made.

The instructions to the patient in the first instance are something like this: "You must hold your breath while I make this exposure. Just breathe quietly until I tell you to stop, then stop breathing and be perfectly still. Now stop breathing—perfectly still, please." Then make the exposure.

The instructions in the second instance are as follows: "I want you to take in a deep breath and then let it out, then hold your breath while I make this exposure. All ready—now breathe in—now breathe out—now hold your breath—perfectly quiet, please." Then make the exposure.

Occasionally a patient will be encountered, usually one whose comprehension is dulled by illness, or an elderly woman, with whom no amount of instruction nor rehearsal will secure the desired result. Then the best that can be done is to have the patient or an assistant hold the patient's nose during the exposure. Such exposures, as well as those of children whose coöperation cannot be secured, must be made as rapidly as possible in an attempt to diminish the bad effects of motion by rapidity of exposure. This usually means that the voltage must be increased with a resultant decrease in contrast on the complete films.

THE IDENTIFICATION OF FILMS.

A Roentgen-ray film should always be marked at the time of exposure so that it can later be identified. Since the films look alike on both sides, this is necessary when parts of the body are exposed that are symmetrical on opposite sides of the body. This applies especially to parts of the skull and the extremities. If films of the nasal accessory sinuses, the mastoid regions, or the jaws, are not so marked, the identification of the right and left sides may occasionally be very difficult—instances have occurred when the fillings in the teeth have been used for purposes of identification. It is important that films of injuries be carefully marked, for no one can tell just when one may be called upon to produce and identify the films as a part of medico-legal testimony.

The best method of providing for the identification of films is to number them at the time of exposure. This can be done by

FIG. 48.—Lead figures and name on films for purposes of identification.

having a lead number fastened to an adhesive plaster strip on the face of the cassette during the exposure (Fig. 48). By a similar use of lead letters R and L, the right and left sides of the body can be designated. The number affixed to the films for each patient should be recorded on an index card, on a copy of whatever report is made of the examination, and on the envelope or folder in which the films are filed.

A simple expedient for determining the right and wrong side of double-coated films has been suggested by Cantrell. He had a small rubber stamp made showing his name and address but reading just the opposite from one used for ordinary purposes. With this stamp, using indelible ink, he stamped his name and address on the margin of the intensifying screen nearest the face of the cassette. The ink destroys the fluorescent action of this screen so that the name appears as distinct letters on developed films. The same result can be secured by using an ordinary rubber stamp and putting

the name on the screen attached to the lid of the cassette (Fig. 48). While this procedure serves to identify a film as unquestionably coming from a particular laboratory, to complete the identification the lead numbers should also be used.

TIMING EXPOSURES.

If the best results are to be obtained, exposures should always be accurately timed. For exposures of a second or longer, this may be done with a metronome, with the second hand of a watch or clock, or, if practice has made one sufficiently accurate, by counting the seconds. A metronome is preferable to a watch or clock, for the tick of the former can be heard while the latter must be observed, thus taking the eyes of the operator from the apparatus or the patient at a time when either or both should be watched. By practicing counting seconds, many operators have become very accurate. The usual practice is to say, either to one's self or audibly, one-thousand-one, one-thousand-two, one-thousand-three, etc., for as long as the exposure lasts. This method should not be used until practice has developed a sufficient degree of accuracy.

To be preferred to any of these methods of timing exposures is the use of a timing device, commonly called a timer, which automatically turns on and off the primary current at the beginning and end of exposures. The accuracy of these devices should never be taken for granted; they should be tested before absolute dependence is placed on them. Testing of the longer exposure times, above one second, can be done with the second hand of a watch; testing those less than a second is somewhat more difficult, yet it can be done with considerable accuracy in any Roentgen-ray laboratory.

The method usually recommended for this purpose is called the spinning-top method. A top, the essential part of which is a circular piece of sheet lead about 2 inches in diameter with a pinhole near the edge, is spun on the surface of a cassette while an exposure is being made. Since the current through the tube is pulsating and Roentgen-rays are produced by each of the pulsations, if the speed of the top has been appropriate, the developed film will show a black spot for each pulsation. In rectified current of 60 cycles, there are 120 such pulsations per second; with the current from a unit type machine, there are 60 pulsations per second. By counting the spots on a film exposed in this manner and dividing by either 60 or 120, depending on the type of machine used, the resulting

fraction will be the exact time of the exposure. For alternating current of a different number of cycles, the number of spots will, of course, be different.

The difficulty with the spinning-top method is in making the exposure when the top is revolving at an appropriate speed. A method that is simpler but one which is used in the same way is to make use of a pinhole in a narrow strip of sheet lead $\frac{1}{2}$ to 1 inch in width and 12 inches in length. If pulled across a cassette by a string attached to one end while an exposure is being made, a row of

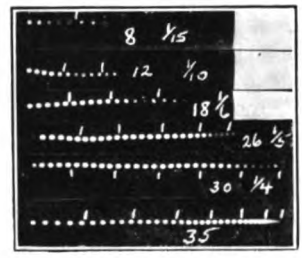

FIG. 49.—Rows of dots made in testing a timer by the method described in the text.

spots similar to those produced by the top will result (Fig. 49). Protecting the rest of the film with sheet lead will permit of making a number of exposures on the same film, during the making of which the speed of the strip across the cassette may be varied.

The importance of testing the accuracy of timing devices may be emphasized by the statement that we have not yet tested one that is absolutely accurate for exposures of less than one-half second, but, by testing, settings that accurately give one-tenth, one-eighth, or one-sixth of a second, etc., have been determined.

STEREOSCOPIC FILMS.

For certain regions of the body stereoscopic Roentgen-ray films possess distinct advantages. In fact it may be said without much exaggeration that, where indicated, stereoscopic films furnish as much more information than single films as single films do over no Roentgen-ray examination at all. Stereoscopic films are particularly indicated in examining regions of the body that contain a considerable quantity of radiopaque material, as the chest, vertebral column, and skull, and in regions where views at right angles to each other are either difficult or impossible, as in examining the upper ends

of the femora and hip joints, or the shoulder. The information yielded by stereoscopic films is so valuable that a Roentgen-ray laboratory doing any considerable amount of diagnostic Roentgen-ray work should not be without the apparatus necessary for exposing and examining such films.

The peculiar value of stereoscopic films lies in the fact that when they are examined there is added to the length and breadth of the plane film a third dimension, depth, of the images shown on them. This gives perspective, making the structures shown appear more nearly their exact shape. On stereoscopic films of the thorax, for instance, the curvature of the ribs is clearly seen, the mediastinal contents and lungs appearing suspended in the interior of the bony thoracic cage; on those of the vertebral column the bodies of the vertebræ appear anterior to the laminæ, pedicles, and articular and spinous processes, so that the smaller parts can be examined for disease or injury by looking through the images of the bodies.

Stereoscopic films are made by exposing two films, with the part of the body and the films in exactly the same position, but with a different position of the anode of the Roentgen-ray tube for each exposure.

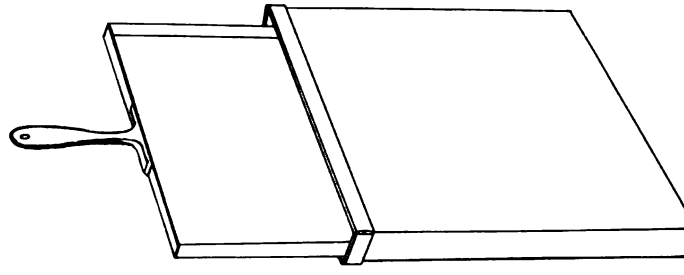

FIG. 50.—A 12- by 12-inch cassette changing tunnel.

If the part of the body is to remain immobile during the exposure of two films, then some device must be used for changing the films without disturbing the part. This is provided for by the use of cassette-changing tunnels (Fig. 50), a stereoscopic shift built into a Roentgen-ray table, or by means of stereoscopic cassette-shifting devices especially made for use in exposing large films. The cassette-holding pan of a Potter-Bucky diaphragm may also be used for the same purpose. In addition to a Potter-Bucky diaphragm, the requirements of a Roentgen-ray laboratory may be met by one or two cassette-changing tunnels, of which the 12- by 12-inch size

is probably the most useful, and an automatic plate changer. For large films requiring rapid exposures the cassette changer may be used; for large films permitting of a long exposure the Potter-Bucky diaphragm should be used; for smaller films of relatively thin parts not requiring the diaphragm, as the knee, shoulder, or foot, the 12- by 12-inch tunnel may be used.

In exposing stereoscopic films, the distance and the direction of the shift of the tube between the two exposures are both of considerable importance. In a measure the distance of the tube shift is controlled by the construction of the stereoscope in which the films are to be examined. These are made with a distance of 25 to 28 inches between the mirrors and the view boxes. For a 25-inch distance between the mirrors and boxes and a 25-inch anode-film distance in exposing the films, the tube shift should be 2½ inches. Two and a half inches is the distance between the pupils of the eyes, a tube shift of this distance or its equivalent being required to produce the stereoscopic effect when the films are examined.

It is best not to expose stereoscopic films at a shorter distance than 25 inches. A longer anode-film distance is permissible, but the tube shift must be increased. In determining the tube shift the controlling factors are the interpupillary distance and that from the mirrors to the view boxes of the stereoscope. The former is 2½ inches, the latter 25 inches; the former is 10 per cent of the latter. If this ratio is maintained, making the tube shift 10 per cent of the anode-film distance, then the ratio between the interpupillary and mirror-view box distances necessary when the films are examined will also be maintained. This establishes the rule for determining the tube shift for making stereoscopic films at a greater anode-film distance than 25 inches: The tube shift should be 10 per cent of the anode-film distance—a 3.5-inch shift for 35 inches, a 4-inch shift for 40 inches, a 6-inch shift for 60 inches, etc. In examining films made by observing this rule, the distance between the mirrors and view boxes of the stereoscope should be 25 inches.

The direction of the tube shift in exposing stereoscopic films is controlled by the direction of the predominating lines in the part being examined. The tube shift should be as nearly as possible at right angles to these lines. In the thorax the predominating lines are the borders of the ribs, so the tube shift should be along the vertebral column. In the vertebræ the predominating lines are formed by the margins of the bodies, the laminæ, the pedicles, and the transverse processes, so the tube shift should be parallel with the

long axis of the column. In making films of long bones the shift should be across the bones; for those of the skull, it may be in either direction, depending on whether structures in the base or vault or in the anterior or posterior regions are being investigated. The direction of tube shift for stereoscopic films will be given in the consideration of the roentgenography of each region.

In exposing stereoscopic films the part of the body is arranged on or in front of the plate-changing device in the same manner as if a plane film were to be made, allowing slightly larger margins of the film to project beyond the part in the direction of the tube shift.

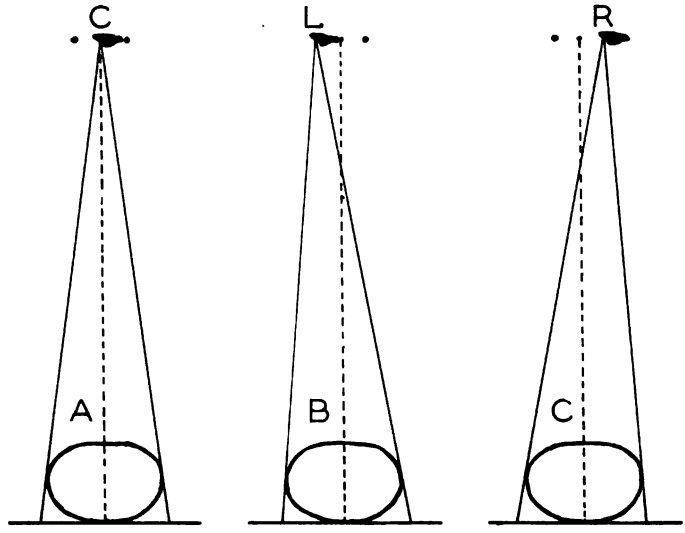

FIG. 51.—The tube shift in stereoscopic roentgenography. A, the tube centered over the part to be exposed; B, the shift of half the distance in one direction for the first exposure; C, the shift of the full distance in the opposite direction for the second exposure.

Center the tube over the part as if a plane film were to be exposed, previously arranging the tube to permit of the necessary shift (A, Fig. 51). For the first film, from the center position move the tube in the proper direction one-half the distance of the shift (B, Fig. 51). It is now in position for the exposure of the first film. When this has been made, for the second film the tube should be moved past the center position an equal distance, and the second film exposed (C, Fig. 51). Except to cover the same area of film when using a small cone, tilting of the tube merely complicates the process and is unnecessary.

Moore describes a method of multiple stereoscopy whereby two sets of stereoscopic films are made on three films. The first and second films are made as in the usual method. The tube is then returned to the position for the first film and from there moved in the opposite direction the required distance and the third film exposed. The first two films will give a stereoscopic pair in one direction, either transversely or longitudinally as the case may be, and the first and third film will give a pair in the opposite direction. Grier recommends the making of three films of the nasal accessory sinuses so that the first and second, and the second and third will make two sets of stereoscopic exposures. Bowen and Bishop describe an ingenious device in the form of a plate or cassette changer by the use of which two or more sets of stereoscopic exposures, as of a joint in both the antero-posterior and lateral directions, may be made on one set of films for simultaneous viewing in the stereoscope. Other devices for special applications of stereoscopic roentgenography have been described.

In exposing stereoscopic films the intensifying screens should have the same speed, the exposures should be exactly the same, and the films should be carried through the different steps of the development together. They cannot be studied with any degree of satisfaction until they are dry.

Since there are many ways of doing so, only one of which is correct, placing stereoscopic films in the view boxes of the stereoscope preliminary to examination should be done with care. In viewing stereoscopic films, the eyes of the examiner, relative to the films, should be in the position of the anode of the tube; thus the images of the part of the body will be viewed from the same aspect as that with which they were made. Films of the chest made with the tube at the back will appear as if the examiner were looking into the thorax from the back; the bodies of the vertebræ will appear in front of the processes on films made in the supine position with the tube anteriorly.

To obtain the correct view, one of the films must be seen with the right eye, the other with the left. To determine which of the two films is to be viewed with the right and left eyes respectively, the films should be superimposed and held in the erect position so that the numbers on them read correctly. By looking through them at a source of illumination it will be seen that the images do not coincide. If the tube shift has been transverse, the image on one film will appear nearer the left margin of the film (B, Fig. 52). This

is the film that belongs to the right eye, the other belonging to the left (A, Fig. 52). If the tube shift has been longitudinal, one of the films will have its image nearer the bottom of the film (A and B, Fig. 53). This film should be viewed with the right eye and the other with the left.

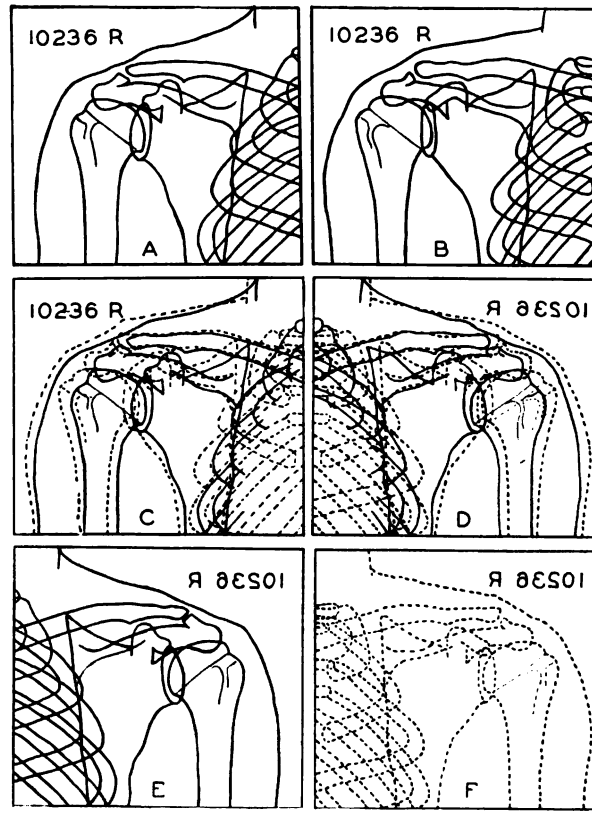

FIG. 52.—Stereoscopic roentgenograms exposed with a transverse tube shift. A, the film for the left eye; B, the film for the right eye. In placing the films in the stereoscope they are superimposed, C; then reversed on a vertical axis, D; the film with the image nearer the right margin is put in the right view box with its right margin toward the front, F; the other film is put in the left view box with its right margin toward the back of the box, E.

Furthermore, in examining the films in the stereoscope, the mirrors will reverse the images, so that if they are to be seen correctly they must be placed in the view boxes reversed.

The directions for placing the films in the proper position in the

stereoscope boxes differ for the two types of tube shift. For those made with a transverse shift, the films are held superimposed with the number reading correctly and viewed in one of the illuminating

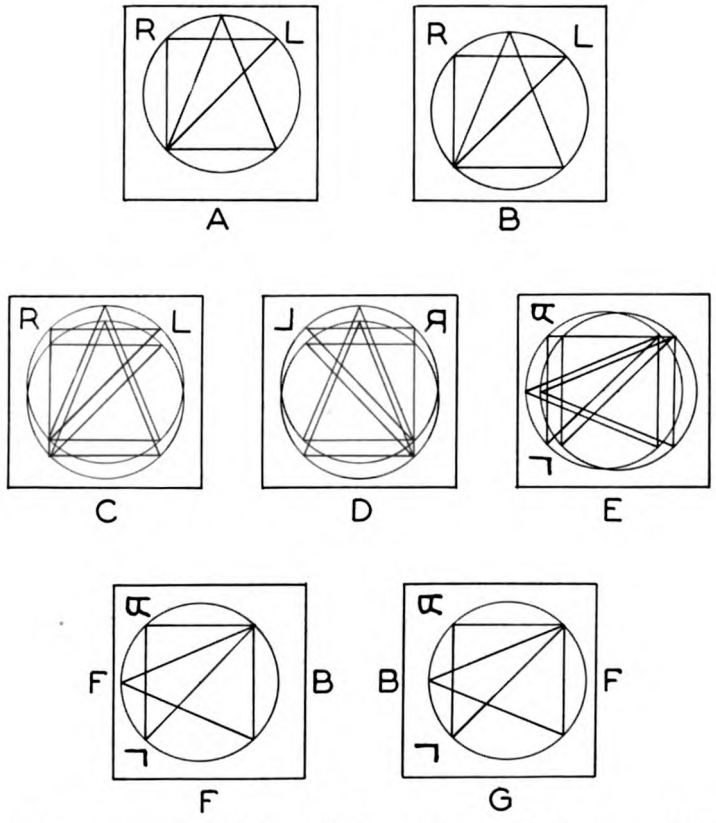

FIG. 53.—An asymmetrical figure illustrating stereoscopic films exposed with a longitudinal tube shift. The one with the image nearer the top, A, is the film for the left eye; the one with the image nearer the bottom, B, is for the right eye. In placing such films in the stereoscope they are first superimposed, C; reversed on a vertical axis, D; then turned a quarter turn with the tops of the films moving to the left, E. In this position the one with the image nearer the right margin is selected and placed in the right view box, with its right margin toward the front of the box, G; the other film is placed in the left view box with its right margin toward the back of the box, F.

boxes (C, Fig. 52). Reverse the images by turning the films over on a vertical axis (D). Select the film on which the image now appears nearer the right-hand margin (F) and place it in the right-hand view box with its right margin toward the front of the box.

Then turn toward the left and place the other film in the left-hand view box (E) with its right margin toward the back of the box.

Stereoscopic films made with the shift along the long axis of the part of the body must be seen in such a way that it appears to be lying on its left side. The films are superimposed with the numbers reading correctly (C, Fig. 53). They are then reversed by turning them on a vertical axis (D) and are also turned a quarter turn so that the tops of the films move to the left (E). In this position the film with the image nearer the right margin is selected (G) and placed in the right-hand view box with the right margin toward the front of the box. The other film (F) is placed in the left-hand view box with its right margin toward the back of the box.

In examining the films the mirrors are slid backward and forward, tilted from side to side, and moved so that the angle between them is either increased or decreased until a single distinct image, with clear perspective, is seen. Since the stereoscopic effect increases as the study continues, the films should not be looked at, but should be minutely studied.

TERMINOLOGY.

The human body is a very complicated structure, one that is continually changing its position and the position of its many parts, and one that is often spoken of and written about. Because of the changes which take place, it has been necessary to establish a particular position for the body and all of its parts and devise a terminology to designate the different aspects and surfaces. These are used for all anatomical descriptions, irrespective of the position the body or any of its parts may be in at the time the description is written. This, often spoken of as the anatomical position, is with the body erect, with the upper extremities hanging at the sides, and with the palms of the hands turned forward.

In this position the aspect of the body in front is spoken of as the anterior aspect or anterior surface; that behind as the posterior aspect or surface. The terms ventral (venter, belly) and dorsal (dorsum, back) are also used interchangeably with anterior and posterior. One exception to this may be noted—the upper surface of the foot is known as the dorsum or dorsal surface. When speaking of the different aspects of the upper extremity, the terms anterior and posterior are used for the arm, the term palmar or volar (vola, palm or sole) for the anterior surface of the forearm and palm of the hand, and the term dorsal for the posterior aspect of the forearm and hand. Because the radius is located under the border of the aspect of the

forearm that supports the thumb, this border is often spoken of as the radial aspect or border. For the same reason the opposite border or aspect is called the ulnar.

The terms right and left, or their Latin equivalents dextra and sinistra or their adjectives dextral and sinistral, are applied to the corresponding aspects of the body. The words medial (medius, middle) or mesial (mesos, middle) and lateral (latus, side) are used to designate parts either nearer to or farther removed from the middle or from the side of the body. Thus the radial aspect of the forearm would be the same as the lateral and the ulnar would be the same as the medial or mesial.

Since the position of the part of the body should always be given in describing a roentgenogram of that part, the practice has arisen of using compound words for designating the different positions. The first part of the word indicates the surface or aspect nearer the Roentgen-ray tube and into which the rays are directed; the second part indicates the surface or aspect in contact with the cassette and from which the rays emerge. For example, the word antero-posterior would indicate that the rays entered the anterior aspect and emerged on the posterior to strike a film in contact with the latter. Other terms such as postero-anterior, ventro-dorsal, dorso-ventral, dorso-palmar, dextro-sinistral, radio-ulnar, etc., are self-explanatory.

Proximal and distal are terms common in anatomy that are being used more and more in general medical descriptions. The term proximal means nearer the trunk of the body or nearer the point of origin or beginning of a vessel, nerve, etc.; distal is the opposite of proximal. Thus the upper extremity of the humerus would be the proximal extremity, the upper would be the proximal phalanx; the lower or inferior end of the humerus and the lower phalanx would be the distal extremity or phalanx, as the case may be.

The terms lateral and transverse are used in designating views made transversely through a part of the body. When used in connection with an extremity or even the trunk, they indicate views made at right angles to the antero-posterior direction. Oblique would apply to views made with the rays directed obliquely. To designate the different oblique views the aspect of the body in contact with the cassette and from which the rays emerge may be used. A right anterior oblique view would be one made with the cassette in contact with the right anterior portion of the chest, the rays being directed into the left side of the body posteriorly. The other oblique views are the left anterior oblique, the left poste-

rior oblique, and the right posterior oblique. These may also be designated as the first, second, third, and fourth oblique positions and views (U. S. Army Manual).

Unless correct anatomical usage is adhered to, considerable confusion may occur with reference to the use of the terms arm and leg. The arm is that part of the upper extremity between the elbow and shoulder; the leg that part of the lower extremity between the ankle and knee. Other major portions of these extremities are the forearm and thigh. If the entire extremity is indicated, it should be so stated. Any other usage of these terms is incorrect and should not be practiced.

THE PREPARATION OF PATIENTS.

The shadows of fecal material and gas in the colon on films of the lumbar part of the vertebral column, the pelvis, or any of the abdominal viscera, often obscure the images of other structures and make interpretation difficult. For this reason the best films will be those exposed when the large intestine is completely empty. This requires, preliminary to many examinations, some preparation of the patient especially to empty the colon of its contents. Unless contraindicated, preparation of this kind should precede examinations of the gall-bladder without the use of an opaque dye, any part of the urinary tract, films of the lumbar vertebræ, films of the sacrum and coccyx, and before the examination of the colon with an opaque enema. The images of the kidneys and the coccyx and distal part of the sacrum are so apt to be obscured that emptying of the colon before examinations of these structures is particularly important.

Attempts to secure a complete emptying of the colon are quite often unsuccessful and there are numerous occasions when they should not be made. In fact, because of poor results, some examiners make no efforts to empty the colon. If the patient is ambulatory and in good condition, the results are usually satisfactory; if the patient is confined to bed, has been ill for some time, has been given drastic purges, or has had morphine for the control of pain, the results are very often unsatisfactory. Weakness of a patient or confinement to bed makes it difficult or impossible to discharge an enema administered for this purpose. Purgation and the administration of morphine probably cause a spasticity of the colon from which it is very difficult to dislodge the fecal material and gas.

Opinions differ as to the best method of securing a complete emptying of the colon. Enemas and laxative or cathartic medicines of various kinds have been recommended. Enemas should be of

large size, from 1½ to 2 quarts; they should be injected slowly and under a low pressure with the container not more than 3 feet above the level of the tip. The patient should be in the supine position and all of the solution should be injected before any of it is expelled. Enemas of lukewarm tap water, water to which a teaspoonful of soda to the quart has been added, and of soapsuds have been suggested. There is some objection to the use of soapsuds because considerable air is held in suspension and is injected with the solution. Enemas of water to which soda has been added are probably as satisfactory as any.

An enema probably should not be used except under circumstances when the condition of the patient warrants the belief that all of it will be expelled, a large intestine partially or completely filled with fluid being more objectionable than one containing some gas and fecal material. If a patient is ambulatory or able to assume the upright position for discharging the enema, preparation by the use of one or more enemas is the most satisfactory. It is doubtful whether a patient that is confined to bed ever completely discharges an enema of large size. Since gas rather quickly reforms in the colon, examinations should be made shortly after the preparation of the patient has been completed.

Drugs that have been recommended for this purpose include compound licorice powder in 1 to 2 tablespoonful doses given in milk, castor oil in doses of from 1 to 2 ounces, and large doses of the saline laxatives. Both castor oil and saline preparations have been objected to on the ground that they cause gas in the colon, one writer objecting to castor oil for this reason and using the salines, another using the salines in preference to the castor oil for the same reason. Magnesium citrate in full doses is probably as good a preparation as any. As with enemas, the examination should be made soon after the laxative has acted.

If a patient has been subjected to considerable purgation a day or two preceding the examination or has had morphine for the relief of pain, attempts to rid the colon of its contents are often unsuccessful. Films made the day following an attack of biliary or renal colic for the relief of which morphine has been used may be so unsatisfactory that a reëxamination is advisable after the effects of the drug have subsided.

With patients that are acutely ill, with those that have been confined to bed for some time, and when there is any contraindication to the use of a cathartic or an enema, examinations should be made without previous preparation.

CLOTHING.

Just a word needs to be said about the clothing worn by a patient during a roentgenographic examination. As far as possible all clothing should be removed from the part being examined. Cotton underwear without buttons or metallic fasteners is unobjectionable. Garments either partly or wholly of silk or rayon should always be removed, for such materials are often impregnated or "loaded" with metallic substances that are sufficiently radiopaque to cause shadows on Roentgen-ray films. I have seen a narrow silk ribbon in the top of cotton underwear cast a shadow equal in density to that of the ribs, and a full silk garment seriously impair detail on Roentgen-ray films. A cotton kimono fastened with strings that tie around the body and constructed so that it may be made to accommodate the girth of the body is a most satisfactory garment to wear during roentgenographic examinations. Several such garments should be kept on hand for use in a Roentgen-ray laboratory. Male patients, when films are made by male examiners, may, of course, be stripped and examined nude.

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CHAPTER XII.

THE UPPER EXTREMITY.

THE HAND.

THE bony framework of the hand is composed of five metacarpal bones and fourteen phalanges. These are classified as long bones, each having a flattened or cylindrical shaft of compact bone and two cancellous extremities. The spade-shaped ungual expansions of the distal phalanges support the nails. The metacarpophalangeal and interphalangeal joints are hinge joints with a considerable range of motion. The carpometacarpal joint of the thumb is freely movable and there is some movement in that of the fifth digit. There is very little motion at the other carpometacarpal articulations.

Any part of any bone of the hand may be injured and require examination. The most common probably are crushing injuries of the ungual expansions of the distal phalanges, transverse fractures of the phalanges near the middle of their shafts, and transverse or oblique fractures of the metacarpal bones.

By placing the palm of the hand on a cassette with the fingers slightly separated, a direct dorso-palmar view of any part of the hand, except the thumb, may be made (Fig. 54)[1]. In this position the bones of the thumb will be shown in a medio-lateral oblique view. Transverse or lateral views, at right angles to the dorso-palmar may be obtained of the bones of the fingers, except the upper halves of the proximal phalanges. In making such views of the fingers, the ulnar aspect of the little finger or the radial aspect of the index finger may be pressed against the cassette with the other fingers flexed into the palm of the hand. For views of the middle and ring fingers,

[1] The photographs of positions given in this and following chapters do not show, in some particulars, all the details of the arrangement of the part and the Roentgen-ray tube used in practice. Care was taken to have the part in the actual position and the Roentgen-ray tube correctly placed, but the anode-film distance may be shorter than that recommended in the text; usually the devices used for immobilization have been omitted. To make the reproductions of the Roentgen-ray films of uniform size, it was necessary to make all exposures lengthwise of the films and to make a single exposure on each film. In many instances this differs from the practice recommended in the text. Except in Figs. 155, 158, and 159, all structures shown on the films are normal.

the cassette may be elevated, the ulnar aspect of the finger placed against it, and the other digits either flexed into the palm or extended dorsally to the one being examined.

To obtain a dorso-palmar view of the thumb it is necessary to flex the thumb at the carpometacarpal joint to a right angle with the palmar surface of the hand, elevate the cassette from the table or place it along the edge of the table, and put the palmar surface of the thumb against the cassette. In this view the proximal end of the metacarpal bone will not be included. A somewhat distorted image of the bones of the entire thumb in the dorso-palmar direction may be

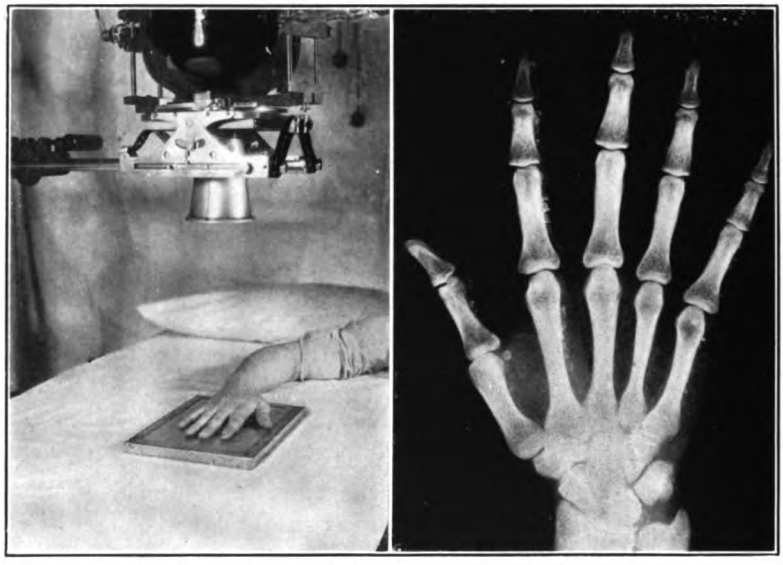

FIG. 54.—Dorso-palmar exposure of the hand.

obtained by flexing the thumb at a right angle with the palm, placing the ulnar margin of the hand on the cassette, and resting the tip of the thumb on some support. A small pasteboard box or a large cork will serve for this purpose. A directly transverse view of the thumb may be made by placing the radial aspect against the cassette, slightly elevating the palm, and bending the fingers to permit the thumb to maintain this position.

If only a part of one digit needs to be examined, such as a distal phalanx, this may be done very satisfactorily by using one or more dental films. In many instances examinations can be made much easier with such material than with larger films.

Directly transverse views of the metacarpal bones and the upper ends of the proximal phalanges of the four fingers are of little value. If the hand is held in the thumb-up position and a film exposed, the images of these bones are so superimposed that the identification of any particular one is difficult. For the second view of the metacarpal region an oblique view, according to the method described by Kress and Payne, should be taken. This is made by placing the ulnar aspect of the hand against the cassette with the dorsal surface of the metacarpal region forming an angle of 45 degrees with its

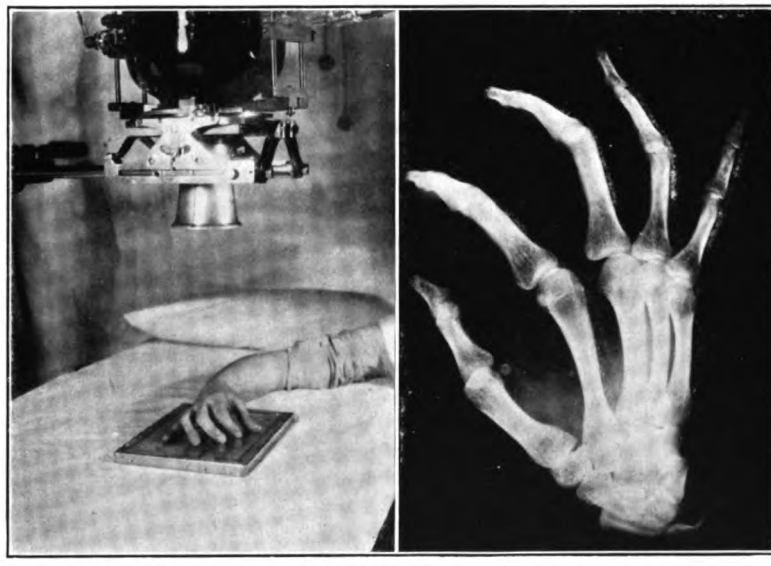

FIG. 55.—Oblique exposure of the hand particularly to show the metacarpal bones in a view differing from the dorso-palmar.

surface (Fig. 55). The little finger may be slightly extended and the other digits flexed so that their tips touch the cassette. Even in this view the images of the proximal ends and parts of the shafts of the metacarpal bones will be partially superimposed.

The size of film required for the proper examination of the hand depends on the definiteness with which the injury or disease can be located. Usually pain or swelling will locate the trouble so that only a small film area is necessary. A $6\frac{1}{2}$- by $8\frac{1}{2}$-inch film divided transversely often suffices. For a complete survey of all the bones of the hand, requiring a dorso-palmar and an oblique view, a larger

film area is necessary—at least the 10- by 12-inch size divided transversely, or two smaller films.

For views of parts of the digits on dental films, the exposure factors as for the anterior teeth may be used, except that the time should be reduced from three to two seconds (page 298).

THE WRIST.

In the wrist are included the eight carpal bones and the distal ends of the bones of the forearm. The carpal bones are arranged in two

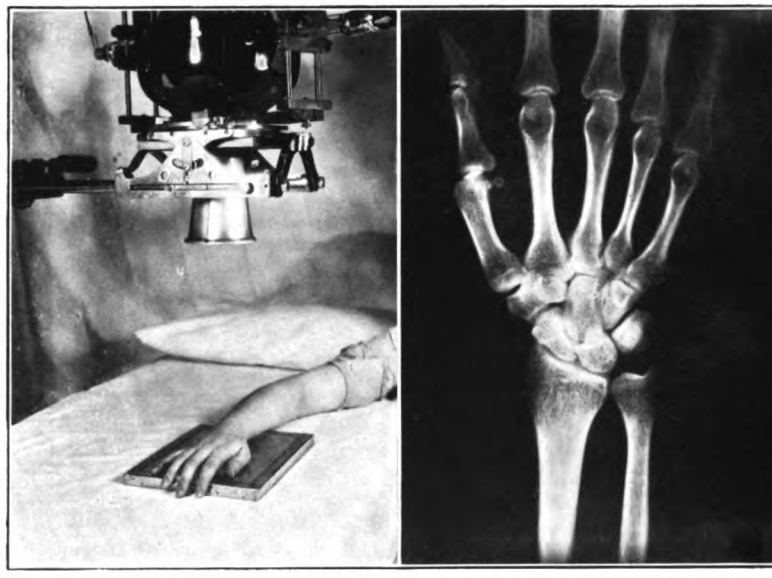

FIG. 56.—Dorso-palmar or postero-anterior exposure of the wrist.

transverse rows. Seen either from above or below, the bones form a curve anteriorly which is converted into a tunnel for the flexor tendons by the transverse carpal ligament. The distal end of the radius is expanded and forms the wrist joint with the proximal row of carpal bones. The distal end of the ulna is quite slender, and is separated from the carpal bones by a thick fibrocartilage. The styloid process of the ulna can be palpated on the medial aspect and that of the radius felt on the lateral aspect of the wrist joint. The joint line forms a proximal curve connecting these two points. The carpal bones can be felt by pressing over the upper limits of

the thenar and hypothenar eminences. Movements in all directions are permitted in the wrist, about one-half of flexion and extension taking place in the radiocarpal and the other half in the intercarpal joints.

Colles' fracture in adults, complicated in about one-half the cases by a fracture of the styloid process of the ulna, is a very common injury. In children fractures of both bones of the forearm in their lower 2 inches and separation of the lower epiphysis of the radius, resulting from the same kind of violence that causes Colles' fracture in adults, are less frequent. Injuries to the carpal bones are rare.

FIG. 57.—Radio-ulnar or lateral exposure of the wrist.

Most common are fractures of the navicular (scaphoid) and a forward dislocation of the lunate (semilunar).

Roentgenographic examination of the wrist should present no difficulties. Dorso-ventral or postero-anterior (Fig. 56) and lateral or radio-ulnar views are required (Fig. 57). Since the displacement in fractures and in the dislocation of the lunate are in the antero-posterior direction, the radio-ulnar or lateral view is the more important and should never be omitted. For both views the tube is centered directly over the radiocarpal joint, for which the transverse grooves in the skin on the front and back of the wrist or either of the styloid processes are good guides. A view made with the back

of the wrist against the plate will show the carpal bones and the spaces between them better than the dorso-ventral view. Only small film areas, either the 6½- by 8½-inch or the 8- by 10-inch size divided transversely, are required.

THE FOREARM.

The radius and the ulna are the two bones of the forearm, the radius being the stronger at the distal end and the ulna at the proximal end. In the anatomical position (complete supination) these bones lie almost in the same antero-posterior plane, the upper end of the radius being but slightly anterior to that of the ulna. The interosseous space between the two bones is wider in the middle of the forearm and in a position of complete supination. In the movement from complete supination (palm forward or upward) to that of complete pronation (palm backward or downward) the radius rotates around the stationary ulna through an arc of 140 to 160 degrees. In the prone position the radius crosses the ulna, the crossing taking place in the upper parts of the bones so that the lower portions are again nearly parallel. The dorsal border of the ulna is subcutaneous throughout its extent. The upper part of the shaft of the radius is deeply placed and, except for the head and neck, cannot be palpated.

Fractures of the bones of the forearm are not uncommon injuries. Both bones are fractured more often than either one alone; fractures of the radius are more common than fractures of the ulna. The displacement and the deformity that occurs in these fractures depends on the kind and direction of the violence, the portion of the bone or bones involved, and the action of the muscles. Careful roentgenographic examination is required to determine accurately the position of the fragments. Views in the antero-posterior and lateral directions, accurately made and at right angles to each other, are required.

The average length of the bones of the forearm is from 10 to 12 inches. For views of both bones throughout their extent either a 10- by 12- or 11- by 14-inch film is necessary. If divided longitudinally and each half exposed separately, the two required views may be shown on the same film. For less than the entire extent of the bones a smaller film may be used.

The antero-posterior view should be made with the forearm completely supinated and with the dorsal surface in contact with

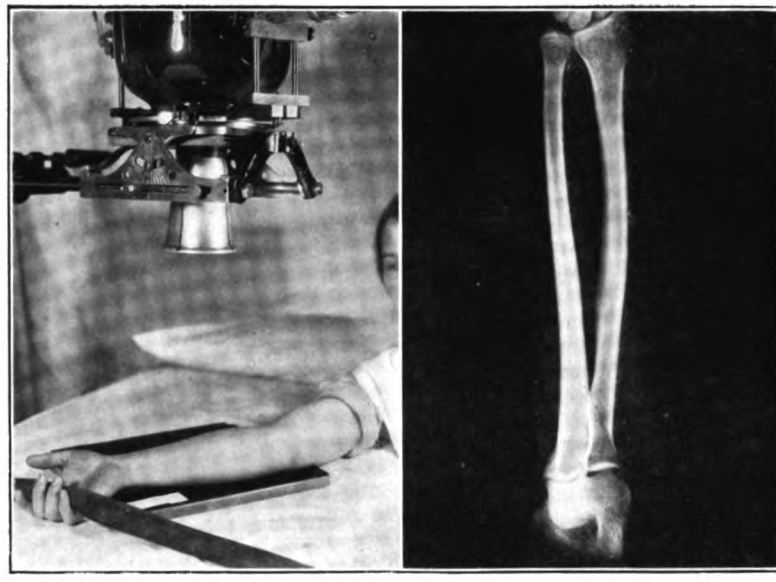

FIG. 58.—Antero-posterior or ventro-dorsal exposure of the forearm.

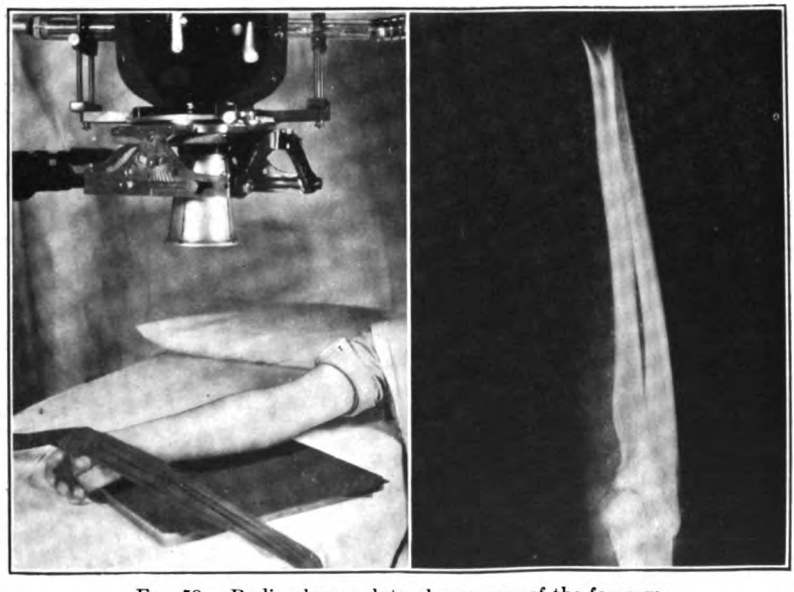

FIG. 59.—Radio-ulnar or lateral exposure of the forearm.

the cassette. The supination should be complete, with the elbow extended and the palm of the hand facing directly upward (Fig. 58). To accomplish this the entire humerus and arm must be in a plane perpendicular to the table top. For the lateral or radio-ulnar view, the position of the forearm mentioned above is maintained and the entire extremity is rotated through the required 90 degrees (Fig. 59). This movement takes place at the shoulder, but greater flexion of the elbow is permissible. The forearm remains in a position of supination with the thumb directed upward. Instead of being in a plane perpendicular to the table top, the humerus must then either be on the table or in a plane parallel with it. To obtain this position, it may be necessary to place an adult patient on a low stool and a child on a high stool at the side of the Roentgen-ray table.

THE ELBOW.

The elbow is composed of the proximal ends of the radius and ulna, the distal end of the humerus, and the joints between them. The elbow joint is composed of three parts—that between the humerus and ulna, that between the humerus and radius, and the proximal radio-ulnar articulation. The upper end of the ulna forms the semilunar notch fitting around the trochlear articular surface of the humerus, supported below by the strong shelf-like coronoid process and behind and above by the equally strong olecranon. The adaptation of the bones is such that the joint is a pure hinge joint, the motions of flexion and extension only being permitted.

In addition to the radial tuberosity, the upper end of the radius is made up of the constricted neck supporting the flattened head. The proximal surface of the head is slightly concave for articulation with the capitulum of the humerus. The margin of the head is received into the radial notch on the lateral aspect of the coronoid process of the ulna, forming the proximal radio-ulnar joint. The joint between the radius and humerus is also of the hinge variety; that between the radius and ulna is classed as a pivot joint. The ligaments holding the radius and ulna together are stronger than those holding the radius to the humerus, thus accounting for the frequency of the dislocation together of both bones of the forearm.

The distal extremity of the humerus is expanded from side to side and flattened from before backward. It is also slightly curved in an anterior direction. At its lowermost part it supports the capitular and trochlear surfaces for articulation with the radius and ulna.

Above these two surfaces on the medial and lateral aspects are the bony prominences called the medial and lateral epicondyles, the medial of which is more distally placed and more prominent than the lateral.

The medial and lateral epicondyles, the olecranon process of the ulna, and part of the head and neck of the radius are subcutaneous and easily palpable. On the dorsal aspect of the elbow a distinct groove separates the lateral epicondyle from the head of the radius. This groove is formed by the radiohumeral articulation which is at the same level as the inferior part of the joint between the humerus and ulna.

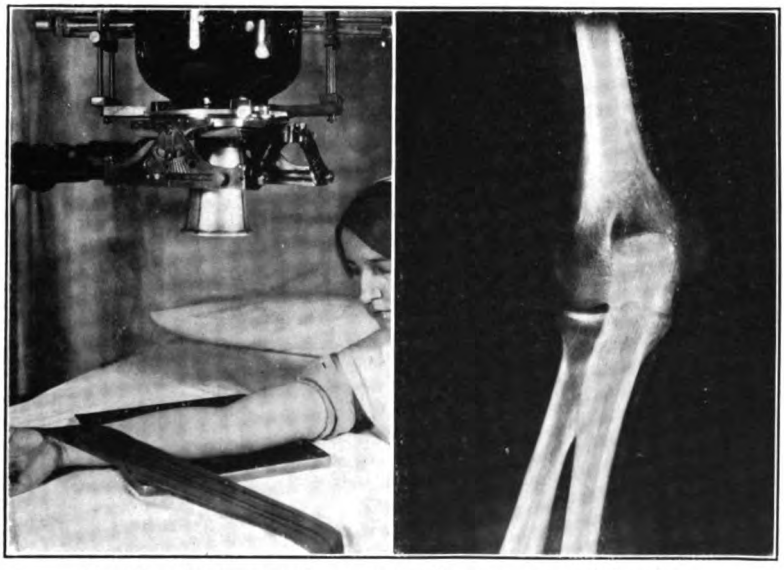

FIG. 60.—Antero-posterior or ventro-dorsal exposure of the elbow.

Any part of the bones about the elbow may be injured and any of the joints may be dislocated, but by far the most common injuries are fractures of the lower end of the humerus, of which there are at least six varieties, fractures of the head of the radius, and backward dislocations of both bones at the elbow joint. Injuries in this region vary in severity from cracks in the head of the radius or in the lower end of the humerus to complete fractures above the condyles with considerable displacement and marked deformity. A patient with an injury in the region of the elbow should not be treated as a sprain

unless a carefully made Roentgen-ray examination has shown the absence of bone injury.

Roentgenograms of the elbow should be made in both the antero-posterior and lateral directions. The ideal antero-posterior view is one that is made with the forearm in the supine position, the elbow completely extended, and the dorsal aspects of both the forearm and arm lying on the cassette (Fig. 60). The lateral or radio-ulnar view may be made through the flexed elbow with the forearm supinated, but with the thumb directed upward and the arm in contact

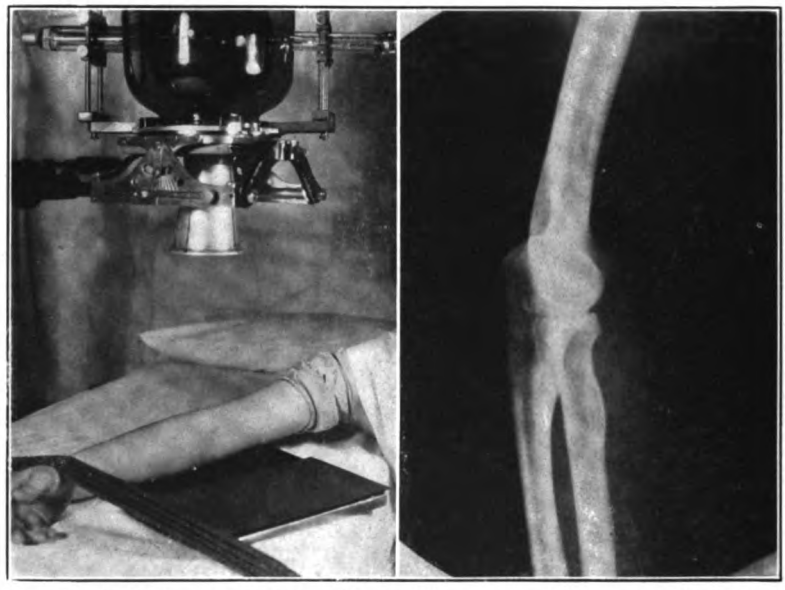

FIG. 61.—Lateral exposure of the elbow. The arm must be as near the table as possible. The elbow may be flexed.

with the cassette (Fig. 61). If the arm is not in this position and the rays are directed perpendicularly to the cassette, the view will be oblique and not as valuable as a true lateral view. Also, if the thumb is not directed upward, the hand being allowed to fall to a prone position, the view of the upper end of the radius will not be at right angles to the other view.

In practice, especially when dealing with severe injuries, the lateral view is easier to secure than the antero-posterior. By moving the extremity and supinating the forearm very slowly, the elbow usually can be arranged in the desired position. It is often

impossible to completely extend the forearm. It is then necessary to take a small film and make two views, one of the bones below and the other of the bones above the joint. In obtaining these, the position of the cassette and the direction of the rays must often be accommodated to the position of the extremity. A well-planned use of sand bags and pillows and tilting of the Roentgen-ray tube will aid materially in obtaining the correct views.

Views of the elbow may be made on small films. The 8- by 10-inch size divided longitudinally is large enough to show the elbow and the adjacent bones. For the antero-posterior view the tube should be centered just below a line connecting the two epicondyles; for the lateral view it should be centered just in front of the lateral epicondyle.

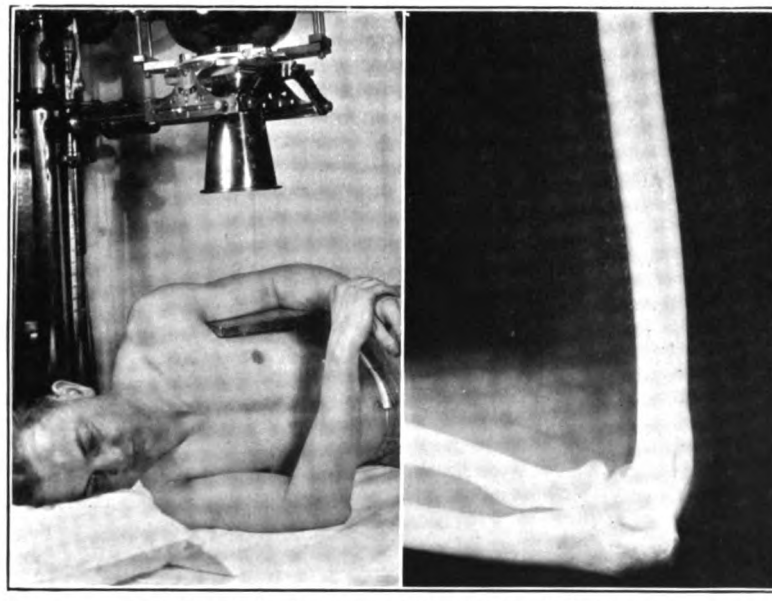

FIG. 62.—Lateral exposure of the distal part of the arm.

THE HUMERUS.

The humerus is the bone of the arm. Next to the femur it is the longest bone of the body, varying in length in adults from 12 to 14 inches or more. The expanded lower end enters into the formation of the elbow joint and has been considered. The shaft is prismatic below and cylindrical above. The upper extremity enters into the

formation of the shoulder joint and will be considered with that region. While injuries of the upper and lower ends of the humerus are common, fracture through the shaft must be classed with the more uncommon bone injuries.

In roentgenography of the shaft of the humerus the accuracy of location of the injury should determine the size of the film to be used. In obtaining the two views at right angles to each other it must be remembered that the humerus may be rotated at the shoulder joint over 90 degrees, and care must be exercised in seeing that the bone is in the same position for the two films. Usually such injuries are so painful that little movement of the arm is permitted. A good practice is to make one view of the humerus with the patient recumbent, then, without moving the arm, rotate the patient to the lateral position with the injured side up (Fig. 62). In this position the cassette may be slipped between the arm and lateral aspect of the thorax for the second view. This may decrease the anode-film distance for the second film so that the exposure factors must be changed accordingly, usually by shortening the exposure time. In the lateral position the upper 4 or 5 inches of the humerus will be above the axillary folds, making it impossible to include them on this film.

THE SHOULDER.

The shoulder joint is formed by the articulation of the upper extremity of the humerus with the glenoid cavity of the scapula. The upper end of the humerus is formed by the greater and lesser tuberosities, separated by the intertubercular (bicipital) groove, and the hemispherical head. The lateral margin of the head at its place of union with the tuberosities is known as the anatomical neck; because of the frequency of injury at that point, the slight constriction where the tuberosities join the shaft is known as the surgical neck.

The glenoid cavity of the scapula is described as pyriform in shape and slightly broader at its upper than at its lower part. In general direction it faces lateralward with a slight inclination upward and forward. It is considerably smaller than the head of the humerus. Overhanging the glenoid fossa above and behind is the acromion process of the scapula; mesially and anteriorly it is overhung by the coracoid process with the coracoacromial ligament connecting the two processes.

The shoulder joint is a ball-and-socket joint, permitting of movements in all directions. Rotation, through an arc of over 90 degrees, is an important movement.

Since the medial epicondyle always points in the direction of the head of the humerus, if the bone is intact, the degree of rotation and position of the head can be ascertained by determining the direction of the medial epicondyle. Thus, with the upper extremity in the anatomical position, both the medial epicondyle and head of the bone are directed medially; but with the elbow flexed and the forearm held across the chest in a sling, the head of the bone extends almost directly backward.

Dislocations of the shoulder are said to be more common than those of any other joint. While this probably is true, the dislocation is recognized and reduced by the attending physician, the patient being sent for examination to detect bone injury, making dislocations rather rare findings in a roentgenologic practice.

Fractures of the upper end of the humerus are of several kinds. They include fractures of the surgical neck, fractures of the anatomical neck, the explosion fracture of Kinney and Elliot, fractures of the tuberosities, and epiphyseal separations. Displacement in different directions with impaction and deformity are quite common. Many will escape detection unless Roentgen-ray examinations are made of all injuries to the shoulder.

The chief problem in roentgenography of the shoulder is to show the humerus in different views in such a way that there can be no doubt as to the kind of injury, the direction and amount of displacement, and the deformity that is present. The most informative single view of the shoulder is one that is taken with the upper extremity in the anatomical position. With the patient in the supine position, the extremity lying at the side and rotated laterally as far as possible, and with the palm of the hand directed upward, the upper end of the humerus will be in the anatomical position (Fig. 63). In this position the head will project mesially and be registered in profile on the film. The lesser tuberosity will extend anteriorly and the greater tuberosity laterally, with the intertubercular groove between them.

The position of the central rays from the tube is of importance. This should be an inch or so medial to the tip of the coracoid process and about the same distance above. The tip of the coracoid can be palpated through the deltoid muscle in the fossa beneath the clavicle and about 1½ inches from its acromial end. This position

of the tube will tend to displace the head of the humerus from under the acromion process.

Views of the upper end of the humerus at right angles to each other are just as important as similar views of any other bone and are probably more informative than stereoscopic films. Considerable difficulty will often be experienced in securing them, and in some instances all attempts will fail. If the humerus can be moved through an arc of 90 degrees without too much pain to the patient, the two views can be secured. The antero-posterior view may be made as described above with the extremity rotated laterally and

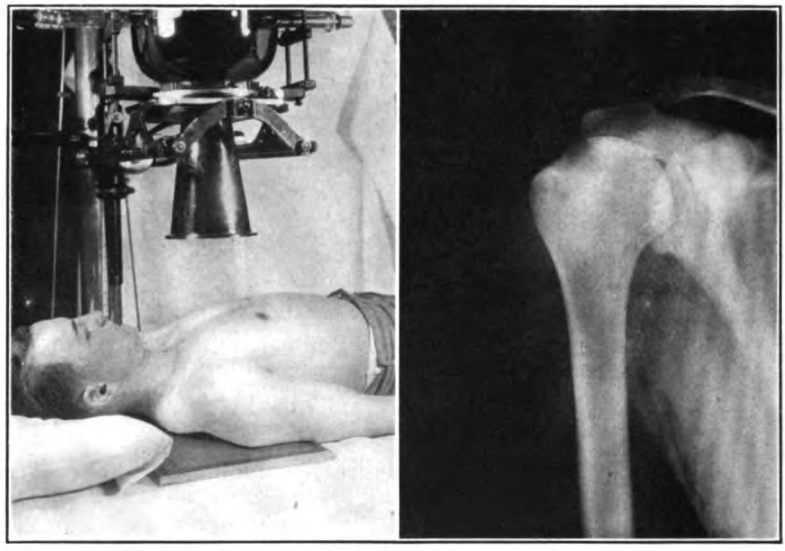

FIG. 63.—Antero-posterior exposure of the shoulder. The extremity is rotated laterally as far as possible with the palm of the hand directed upward.

the medial epicondyle projecting directly medially. Then if the forearm is pronated and the arm medially rotated until the medial epicondyle projects directly backward, a second view may be exposed which will be a lateral view through the upper extremity of the humerus.

An ambulatory patient with an injured shoulder usually comes with the elbow flexed and the forearm held in a sling across the chest. The patient may be placed in the supine position on the table, the elbow brought forward and supported on a pillow so that the forearm is parallel with the table. If a film is exposed with the

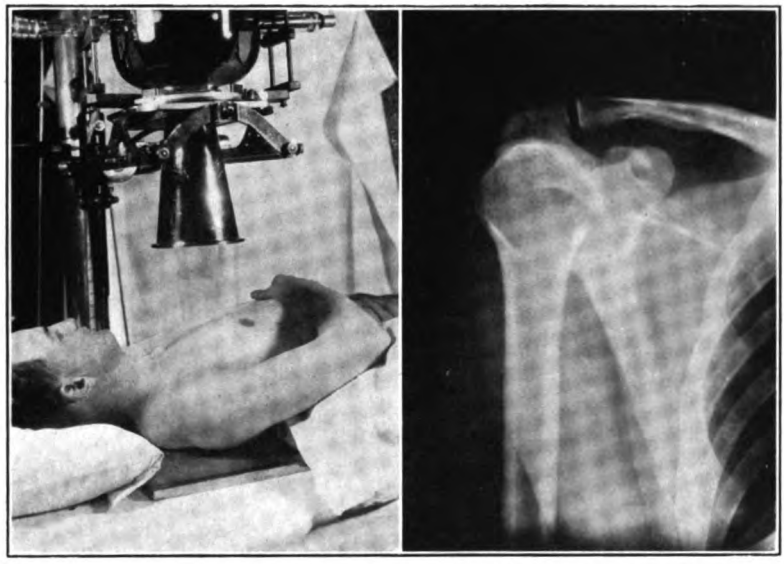

FIG. 64.—Antero-posterior exposure of the shoulder with the forearm flexed across the trunk, giving a lateral view of the proximal extremity of the humerus.

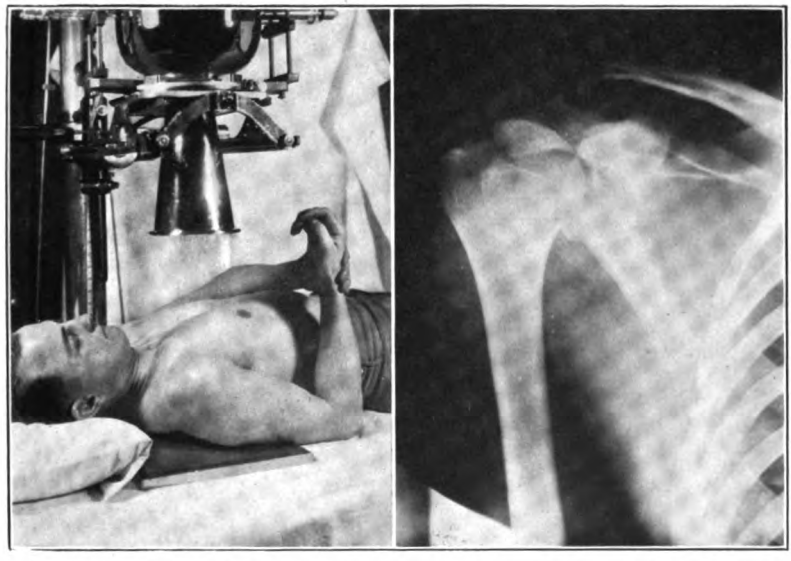

FIG. 65.—Antero-posterior exposure of the shoulder. With an injured shoulder, if it is possible to move the extremity from the position in Fig. 64 to that shown in this illustration, two views of the proximal end of the humerus may be obtained.

of the tube will tend to displace the head of the humerus from under the acromion process.

Views of the upper end of the humerus at right angles to each other are just as important as similar views of any other bone and are probably more informative than stereoscopic films. Considerable difficulty will often be experienced in securing them, and in some instances all attempts will fail. If the humerus can be moved through an arc of 90 degrees without too much pain to the patient, the two views can be secured. The antero-posterior view may be made as described above with the extremity rotated laterally and

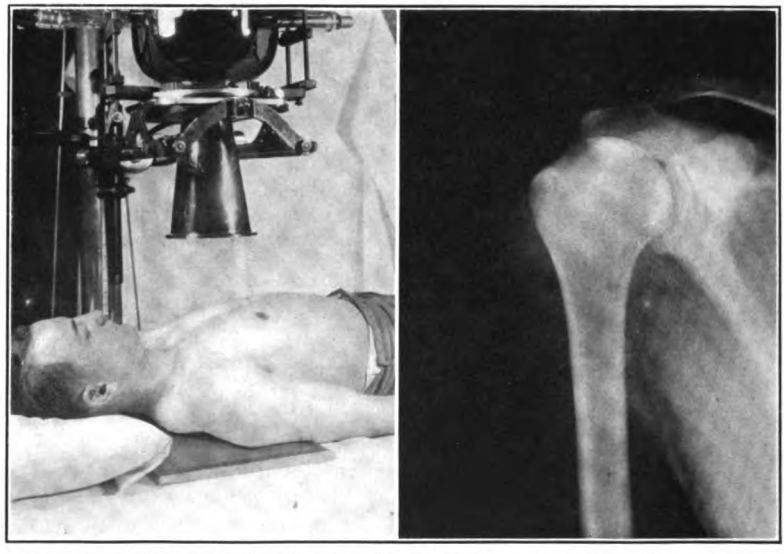

FIG. 63.—Antero-posterior exposure of the shoulder. The extremity is rotated laterally as far as possible with the palm of the hand directed upward.

the medial epicondyle projecting directly medially. Then if the forearm is pronated and the arm medially rotated until the medial epicondyle projects directly backward, a second view may be exposed which will be a lateral view through the upper extremity of the humerus.

An ambulatory patient with an injured shoulder usually comes with the elbow flexed and the forearm held in a sling across the chest. The patient may be placed in the supine position on the table, the elbow brought forward and supported on a pillow so that the forearm is parallel with the table. If a film is exposed with the

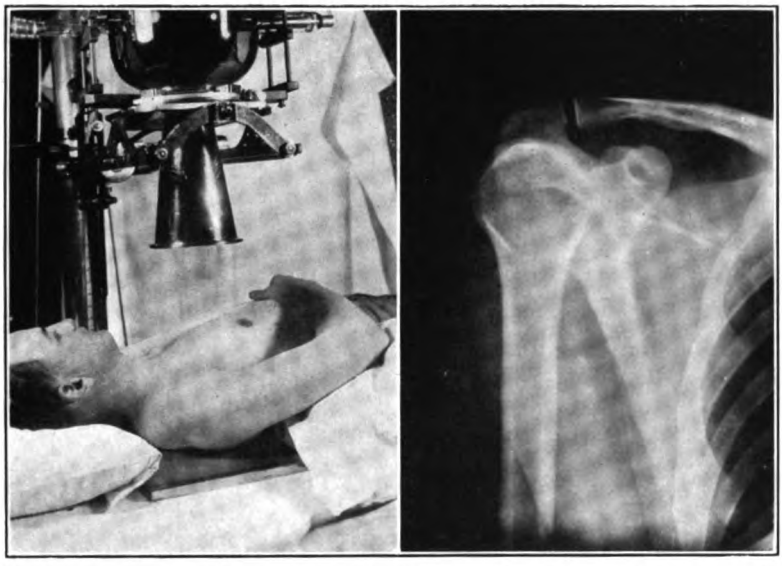

FIG. 64.—Antero-posterior exposure of the shoulder with the forearm flexed across the trunk, giving a lateral view of the proximal extremity of the humerus.

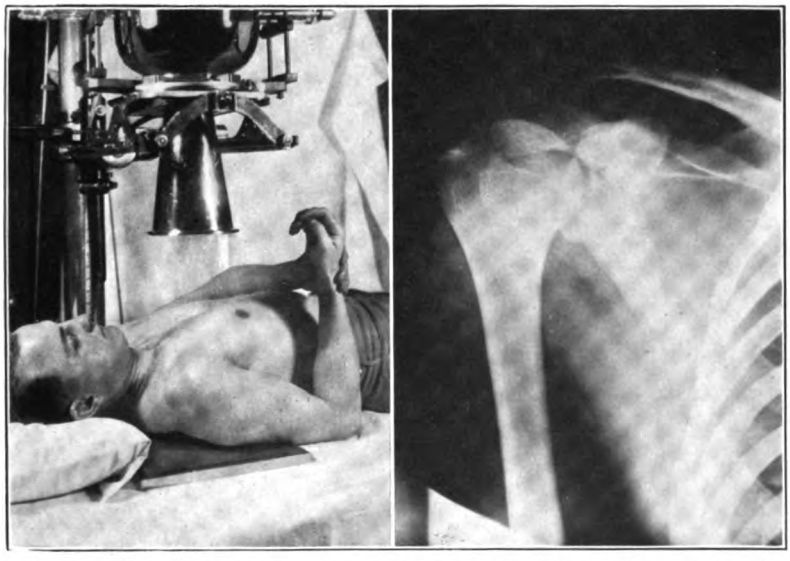

FIG. 65.—Antero-posterior exposure of the shoulder. With an injured shoulder, if it is possible to move the extremity from the position in Fig. 64 to that shown in this illustration, two views of the proximal end of the humerus may be obtained.

extremity in this position, a lateral view of the upper end of the humerus will be secured (Fig. 64). Then if the humerus can be rotated laterally through an arc of 90 degrees, the arm will be in the anatomical position and the antero-posterior view may be exposed (Fig. 65).

By abducting the upper extremity to a right angle with the trunk, placing the cassette on the axillary aspect of the arm, and directing the rays from above downward, the second view of the upper end of the humerus may be taken. Tilting the tube at a slight angle

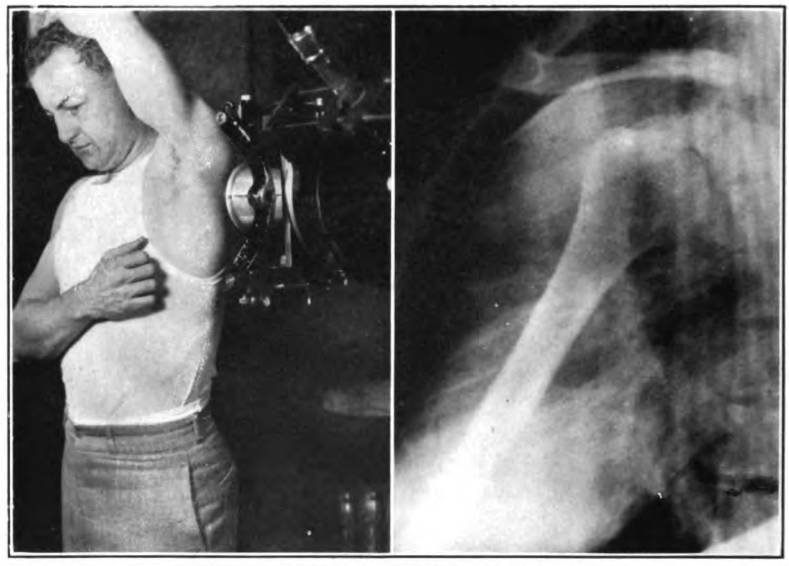

FIG. 66.—An antero-posterior exposure of the proximal end of the humerus taken through the upper part of the thorax. The exposure in Fig. 64, with the one in this illustration, gives two views of the proximal end of the humerus. In fractures these are preferable to stereoscopic films.

laterally will displace more of the shoulder on to the film and will not cause enough distortion to impair the result. Or the position of the tube and cassette may be reversed as suggested by Lawrence by placing the cassette on top of the shoulder and directing the rays from below upward through the axilla.

If it is not possible to move the shoulder, the lateral view may be taken with the forearm across the chest as already described and the antero-posterior view through the upper end of the humerus taken by the second method described by Lawrence. This consists of

having the patient either sit or stand, without changing the position of the extremity, with the injured shoulder, slightly drooping, pressed against a cassette-holding device. The opposite extremity is held above the head. The tube is turned horizontally and the rays directed into the opposite axilla (Fig. 66). The patient is instructed to take a full inspiration and hold the breath while the exposure is made. In this manner a view of the upper end of the humerus is taken with the rays passing through the upper part of the thorax. The bone will be shown clearly enough to depict any displacement or deformity.

THE CLAVICLE AND SCAPULA.

The clavicle is a rather slender bone shaped somewhat like the italic letter *f*, curving forward in its medial part and backward in its lateral part. It connects the scapula with the sternum and is the only bony connection between the upper extremity and the trunk. It is subcutaneous throughout its extent and can be readily palpated.

The clavicle was formerly said to be the most frequently fractured of any bone of the body, and now that self-starters are a part of all automobiles, eliminating fractures of the radius from motor back-firing, it has probably regained its former prominence. It may be fractured by direct violence in any part of its extent. Since the outer third of the clavicle is attached to the scapula by powerful ligaments, fractures by violence applied to the upper extremity or shoulder are uniform in location at the junction of the middle with the outer third. Green-stick fractures in children are common. Dislocations of either the acromial or the sternal end are rather uncommon, those of the former being more common than those of the latter.

When the clavicle is fractured, the medial end is not much displaced; the displacement of the lateral end is always downward and forward. The constancy of the displacement and the fact that much information concerning the position of the fragments can be obtained by palpation usually make unnecessary more than a single view of the clavicle. Postero-anterior views are preferable to those made in the supine position. The patient is placed in the prone position with the upper extremity of the injured side along the trunk and the head turned toward the opposite side. The cassette, either the 6½- by 8½- or the 8- by 10-inch size, is placed under the injured clavicle with the long axis corresponding to that of the bone and the

tube centered over the spine of the scapula behind (Fig. 67). It is important that respiration be stopped during the exposure. The supine position is one that it is often necessary to use with children, the antero-posterior views thus obtained being but slightly less valuable than those made in the prone position.

Quesada recommends two exposures of injuries to the clavicle, one obliquely from above downward and the other from below upward, the central rays for the two exposures directed at an angle of 90 degrees with each other. Views made in this manner are at right angles to each other and accurately show all displacement that

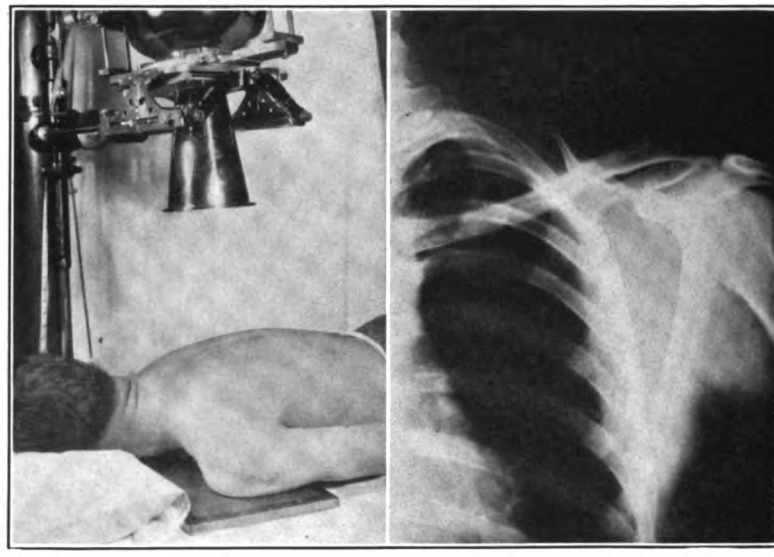

FIG. 67.—Postero-anterior exposure of the shoulder to show the clavicle. The injured side is against the cassette with the head turned over the opposite shoulder.

is present. He uses a device in the form of a quadrant of 90 degrees with an arm at each end to direct the central rays. The degree scale on the arm of most Roentgen-ray tube stands may be used for the same purpose.

In direct postero-anterior films the sternal end of the clavicle is somewhat obscured by the shadows of the thoracic vertebræ. When this part of the bone is being examined the cassette should be placed farther medially and the rays directed at an angle of 10 to 15 degrees toward the midplane of the body. This will give views of the sternal end not covered by the shadow of the spine. Because

the sternal end of the clavicle is covered by the shadows of the ribs, when seeking for evidences of disease, postero-anterior stereoscopic films should be taken.

The scapula is a somewhat irregular, triangular-shaped bone forming the posterior part of the pectoral girdle. The spine extends across its posterior surface ending in the acromion process. The glenoid fossa is supported on a constricted portion called the neck. The coracoid process extends upward and then forward, medial to the glenoid cavity. The only connection of the scapula with the bones of the trunk is through the clavicle. It is surrounded and well

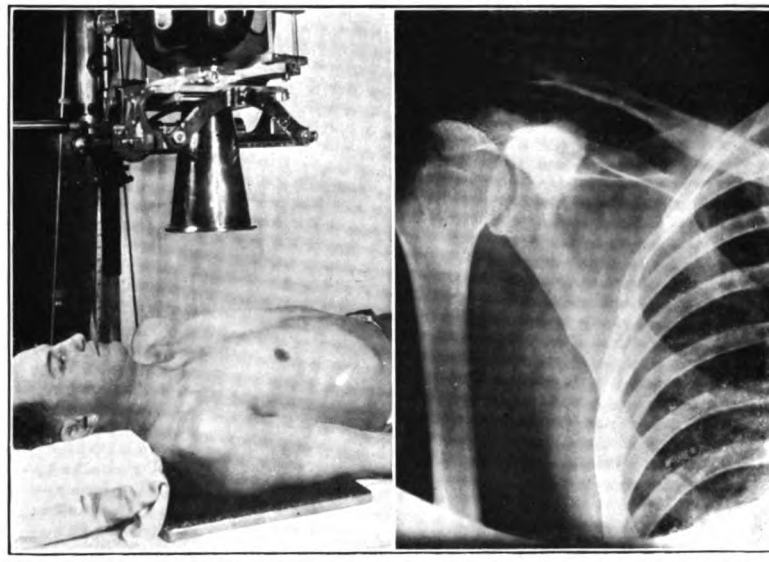

FIG. 68.—Antero-posterior exposure of the scapula. The opposite shoulder is elevated on a sand bag.

padded with muscles and is freely movable. Because of its protection by muscles and its mobility, injuries to the scapula are uncommon. Fractures of the acromion, the neck, and the body both above and below the spine are occasionally encountered.

Films of the scapula should be made with the patient in the supine position with the cassette, either the 8- by 10- or 10- by 12-inch size, beneath the shoulder. The injured side should be thrown well back and the opposite shoulder elevated on a sand bag or pillow to bring the body of the bone parallel with the film (Fig. 68). To detect displacements of fractures in the antero-posterior direction, almost

an exact lateral view may be made by rotating the shoulder forward as far as possible and making an exposure obliquely from behind outward and forward (see Fig. 89). The patient may be in either the erect or prone position.

Stereoscopic films of the scapula are always preferable to plane films.

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CHAPTER XIII.

THE LOWER EXTREMITY.

THE FOOT.

THE bony framework of the foot is composed of seven tarsal bones, five metatarsal bones, and the fourteen phalanges of the toes. Except those for the great toe, the phalanges are small with slender shafts and expanded extremities. The distal ends of the distal phalanges present ungual expansions for the support of the nails. Of the metatarsal bones, the first is the heaviest and also the shortest; the second is the longest. The fifth has a rough tuberosity on the lateral aspect of its proximal end.

The tarsal bones vary considerably in size, and have an irregular arrangement. They assist in forming the arches of the foot. The posterior part of the longitudinal arch, formed by the calcaneus, is shorter than the anterior, which, in the tarsal region, is formed by the navicular, cuboid, and three cuneiform bones. The cuneiform and cuboid bones, with the proximal ends of the metatarsal bones, form the transverse arch. The talus (astragalus) is placed at the apex of the longitudinal arch, forming the ankle joint with the inferior articular surfaces of the tibia and fibula.

On the dorsal and lateral aspects of the foot the bones lie near the surface; on the plantar and medial aspects they are covered with thick skin and fascia and a considerable layer of muscles. On the medial aspect of the foot the tuberosity of the calcaneus, the tuberosity of the navicular, and the first metatarsal bone are all palpable. On the dorsal aspect the individual metatarsal bones can be made out nearly to their proximal extremities. The individual tarsal bones cannot be distinguished. On the lateral aspect the calcaneus is subcutaneous. The expanded proximal end of the fifth metatarsal bone can be palpated, proximal to which lies the cuboid. Except for flexion and extension of the ankle and toes, movements of the foot are limited to inversion and eversion which take place in the intertarsal articulations.

Fractures of the phalanges of the toes and of the metatarsal bones

by direct violence, usually by a heavy object dropping on the foot, are rather common. Such injuries of the phalanges of the great toe and of the metatarsal bones are more common than similar injuries of the other bones. The metatarsal bones, usually the fifth, may be fractured by forceful inversion or eversion of the foot. Fractures of the tarsal bones are rather uncommon, those of the calcaneus and talus from falls or jumps alighting on the heel being the usual form.

Roentgenography of the foot is complicated by the irregular arrangement of the bones, by the close contact of the bones with each other, making views at right angles often impossible, and by the variations in the thickness of the foot, especially in the dorso-plantar position. The more common views include the dorso-plantar view of the bones anterior to the talus, a lateral view of the entire foot, an oblique view from below upward, an antero-posterior view of the ankle showing the talus, and an oblique view from behind and above downward and forward through the posterior part of the calcaneus.

A dorso-plantar view shows the bones of the toes, the metatarsal, and the tarsal bones anterior to the talus, including the navicular, cuboid, and the three cuneiform bones. Since the bones of the leg are above the posterior two tarsal bones, they cannot be included. This view is made by flexing the knee, extending the ankle, and resting the sole of the foot on the cassette, directing the rays perpendicularly to the surface of the cassette or at an angle of 10 degrees toward the heel with the central rays centered just lateral to the most prominent part of the instep (Fig. 69). This is over the proximal end of the third metatarsal bone or the upper surface of the third cuneiform bone. One-half of an 8- by 10-inch film, divided transversely, is large enough for this view.

Because of the variations in thickness, it is impossible to show all of the structures with the same density on a dorso-plantar view of the foot. Exposure factors that will give the optimum density to images of the bones of the toes and heads of the metatarsal bones will result in an underexposure through the tarsal region. On the other hand, factors correct for the tarsal bones will overexpose the images of the smaller bones. For this reason, in a thorough examination of the foot it is advisable to make one exposure to show the heads of the metatarsal bones and the phalanges, and a second view on the other half of the same 8- by 10-inch film especially to show the proximal ends of the metatarsal and the tarsal bones.

In a directly lateral or transverse view of the foot, the calcaneus,

talus, navicular, and cuboid are shown without being much obscured by other bones, but the cuneiform and metatarsal bones are superimposed so that the individual images cannot be identified. For this view an area of film at least 10 inches long and 4 inches wide is required. It is made by placing either the medial or lateral margin of the foot against the casette with the tube focused halfway between the heel and tip of the great toe.

An oblique view of the foot is better than one in the lateral projection. It is made by placing the lateral aspect of the foot

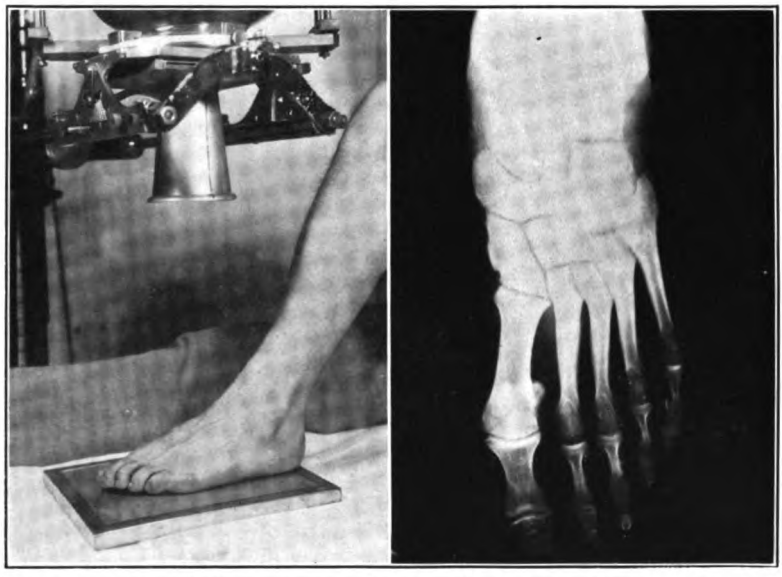

FIG. 69.—Dorso-plantar exposure of the foot. To show the toes and the proximal ends of the metacarpal bones and the carpal bones without over or underexposure, two views with different exposure factors are required.

against the cassette with the entire lateral aspect of the ankle and leg resting on the table. The foot is inverted as much as possible. The inversion permitted at the heel is rather slight, but a considerable turning of the metatarsal bones and toes is possible. In the proper position the sole of the ball of the foot is directed obliquely upward (Fig. 70). It should be held in this position with a double sand bag. The view obtained by this position will be an oblique one of the anterior bones, separating the images of the different structures so that all of them can be identified. The same size

film and similar focusing of the tube are required as for the direct lateral view.

Because of the shape of the three cuneiform bones, their close apposition, and the fact that the proximal end of the second metatarsal bone fits between two of the cuneiform bones, it is impossible in any position to obtain clear-cut images of these bones in two directions. Fortunately injuries in this region are very rare.

The talus (astragalus) is well shown in lateral views of the foot. For the second view, since a dorso-plantar view of more than the head is impossible, dependence must be placed on a direct antero-

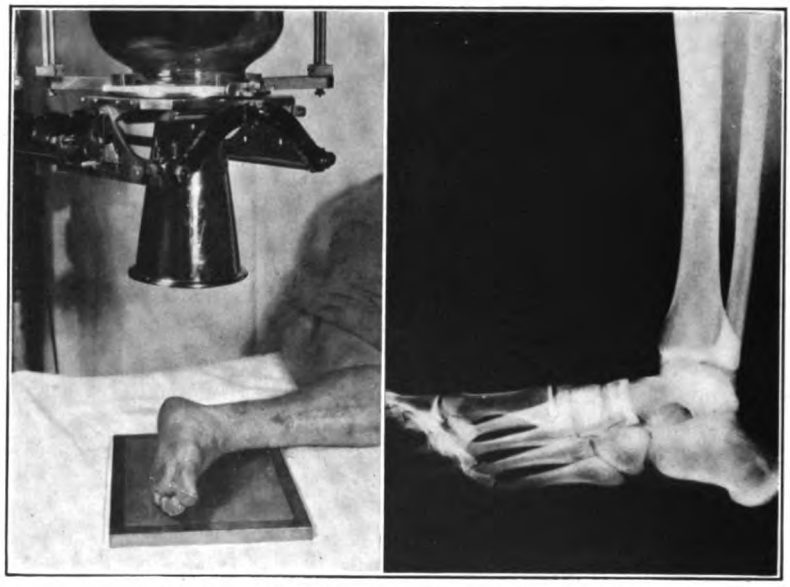

FIG. 70.—Oblique infero-superior exposure of the foot.

posterior view through the ankle joint (Fig. 72). This shows the upper surfaces and lateral margins of the bone, but the neck and the head are poorly delineated.

The calcaneus is included on a lateral view of the foot, but a special view is necessary for showing it in a second projection. This is an oblique view from above downward and forward through the heel. For it, the patient is placed in the prone position on the table, with both ankles flexed to a right angle or as near that as the injured side will permit. The cassette, 8- by 10-inch size, is placed on end against the soles of the feet. The rays are directed from

above downward and toward the toes at an angle of 35 to 45 degrees (Fig. 71). The tube is focused over the heels and midway between them. Both heels are included so that the injured side may be compared with the uninjured one. Since a fracture of the calcaneus is the most common of the fractures of the tarsal bones, often is a disabling injury, and the displacement may be either medial or lateral, in case of injury to the heel this view should never be omitted.

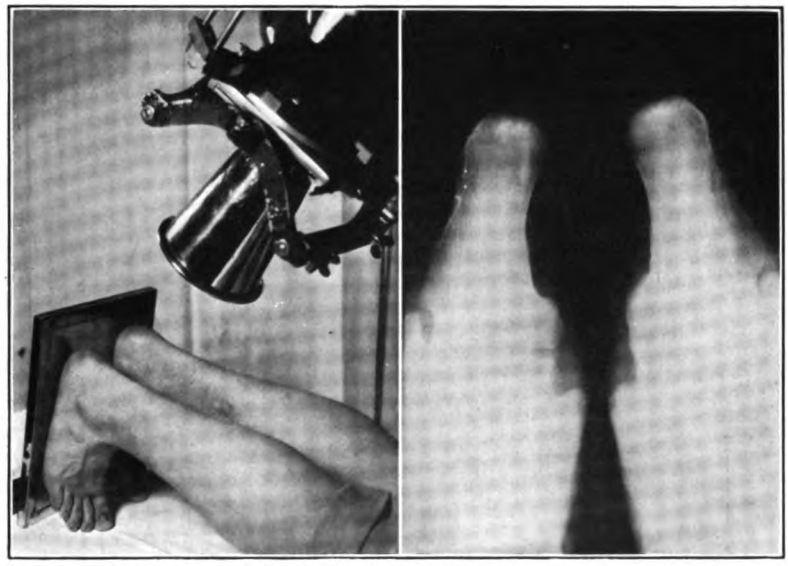

FIG. 71.—Oblique supero-inferior exposure of the heels. To show lateral displacements in fractures of the calcaneus (os calcis), this view is necessary.

THE ANKLE.

The ankle joint is a pure hinge joint between the talus (astragalus) of the tarsal bones and the lower ends of the tibia and fibula. The joint is bracket-shaped, with a horizontal part between the lower end of the tibia and talus, and two vertical parts between the talus and the articular surfaces of the medial and lateral malleoli. The malleoli at the sides of the joint are quite prominent and are subcutaneous, the lateral being smaller, more distinct, and projecting $\frac{1}{2}$ inch farther distally than the medial. The posterior borders of the two are in the same transverse vertical plane. The line of the horizontal part of the ankle joint is $\frac{1}{2}$ inch above the tip of the medial malleolus.

Injuries of the structures in and around the ankle joint are quite common. They vary in severity from a slight rupture of some of the ligaments and laceration of the synovial sheaths to extensive fractures of the lower ends of both bones of the leg with dislocations of the foot at the ankle joint. The most common injury with a fracture is probably Pott's fracture in which there is a break in the lower third of the fibula, either a rupture of the medial ligaments of the ankle or a fracture across the base of the medial malleolus, associated with a lateral dislocation of the ankle. In cases of injury to the ankle, fractures through the lower part of the fibula,

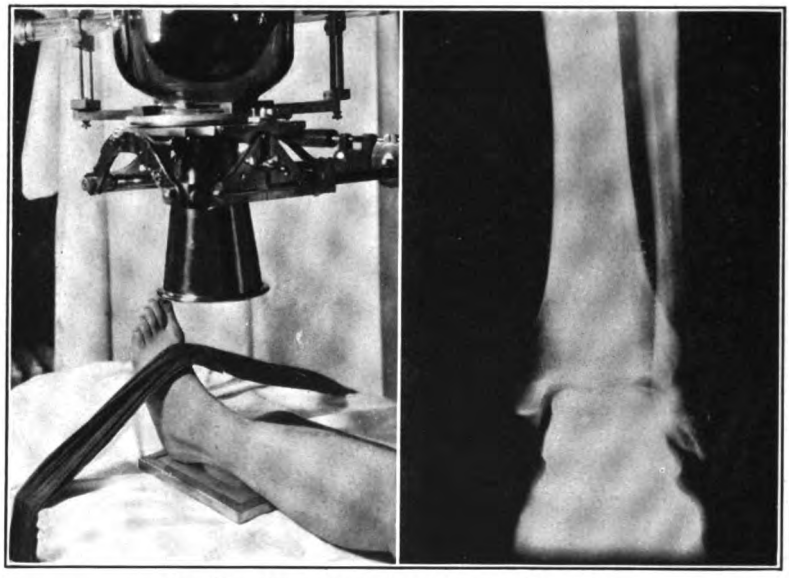

FIG. 72.—Antero-posterior exposure of the ankle.

often oblique and not seen on the antero-posterior view, fractures of the medial malleolus, slight dislocations at the ankle in either of the four directions, and inversions and eversions of the foot should all be kept in mind. A careful Roentgen-ray examination of many injuries clinically diagnosed as sprains will show small fragments of bone broken off of one of the malleoli.

Roentgenograms of the ankle should always be made in both the antero-posterior and lateral directions. To detect injuries to the lower part of the fibula, the distal thirds of both bones of the leg should be included on both views. In the antero-posterior view

the heel should rest on the cassette near the margin with the foot flexed to a right angle with the long axis of the leg (Fig. 72). The tube is focused over the ankle joint or slightly above this level. The lateral view is made with the lateral aspect of the ankle and lower part of the leg in contact with the cassette, with the rest of the leg in contact with the table (Fig. 73). The tube is focused over the most prominent part of the medial malleolus.

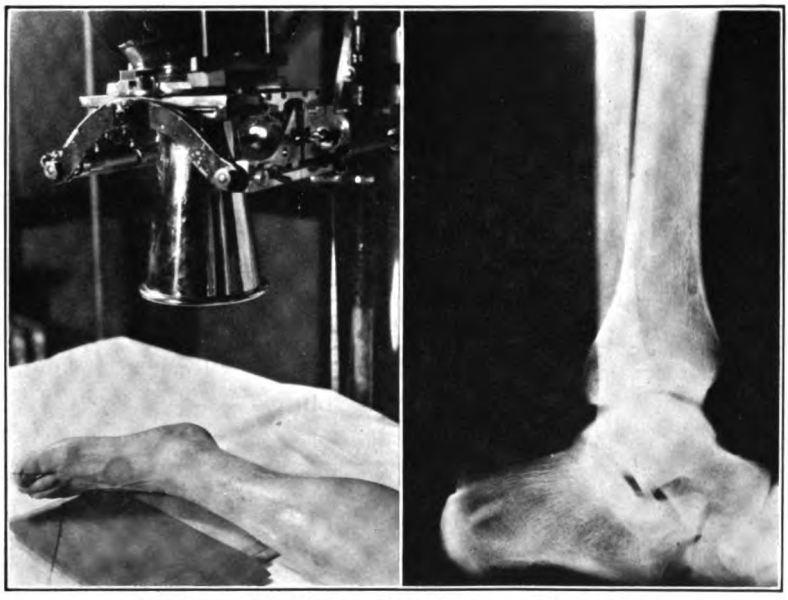

FIG. 73.—Tibio-fibular or lateral exposure of the ankle.

An 8- by 10-inch film divided transversely is usually sufficient for both views of the ankle. Immobilization with a double sand bag or other device is important. If another injury of the patient prevents turning the leg for the lateral view of the ankle, the leg may be elevated on a small pillow, the cassette placed on edge, and the rays directed horizontally.

THE LEG.

The tibia and fibula are the bones of the leg. The tibia is located medially and the fibula laterally and slightly posteriorly. They are of about the same length. The tibia is considerably larger and stronger than the fibula. It is largest at the upper end, gradually

decreases in size from above downward to the junction of the middle and lower thirds of the shaft, expanding again at the lower extremity. Except for the expanded extremities, the fibula is of uniform size throughout. The bones of the leg are not in the same transverse plane. The proximal tibiofibular articulation is at the postero-lateral angle of the expanded upper end of the tibia. In the middle of the leg the shaft of the fibula is in a position distinctly posterior to that of the shaft of the tibia. Toward the ankle the fibula inclines forward so that at the joint it lies directly lateral to the tibia (Fig. 70).

The proximal and distal ends of the fibula are palpable for a distance of from 3 to 4 inches; the middle of the bone is deeply buried in the muscles of the leg. The anterior border or shin of the tibia and all of the medial surface are subcutaneous, the latter being continuous with the subcutaneous surface of the medial malleolus.

Fractures of the bones of the leg are rather common. The most frequent injury is of the lower end of the fibula associated with a Pott's fracture, or with a similar injury due to inversion of the foot. Next most common is a fracture of both bones of the leg at or near the junction of the lower with the middle third. The fracture of the fibula is usually somewhat higher than that through the tibia. Because of its more exposed position, the tibia may be fractured alone. Less frequent injuries may involve any part of either bone. An interesting and not rare lesion is a vertical or very oblique crack in the tibia of a child without external manifestations, the only symptom of which is pain.

Roentgenograms in the antero-posterior and lateral positions are required for an examination of the bones of the leg. To show both in the antero-posterior view, the posterior aspect of the leg is placed in contact with the cassette with the foot and toes directed vertically upward. For the lateral view the patient may be turned to the lateral position with the lateral aspect of the leg against the cassette and the foot horizontal. Because of the posterior position of the shaft of the fibula, the shafts of both bones will be shown without much overlapping of their images on both these views.

If both bones of the leg are injured and encased in a temporary dressing or splint, it is often advisable to make the lateral view by slightly elevating the limb, propping the cassette in a vertical position along the mesial aspect of the leg, and directing the rays horizontally (see Fig. 77).

For showing both bones of the leg of an adult in their entire extent in both directions a 14- by 17-inch film divided longitudinally is necessary. The tube should be centered over the middle of the leg. Because the location of the injury can usually be rather accurately determined, such a large film is rarely necessary. Usually the 10- by 12- or the 11- by 14-inch size divided longitudinally is sufficient. The region of the injury should be placed near the middle of the cassette and the central rays directed as nearly as possible through it. The fact that the fibula is usually broken at a higher level than the tibia should be remembered.

Occasionally an extremity will be encountered that is thin through the ankle and just above and thick through the prominent part of the calf and upper part of the leg. Exposure factors for films through the thinner part will not be appropriate for the thicker part. For an examination of the entire leg it is then advisable to use two films, 10- by 12-inch size divided transversely, one for the thicker and one for the thinner part, with different exposure factors for each part.

The positions of the extremity for films of the leg are similar to those for the ankle shown in Figs. 72 and 73.

THE KNEE.

The region of the knee is formed by the expanded extremities of the femur and tibia with the upper end of the fibula and the patella. The fibula articulates with the posterior part of the lateral aspect of the lateral condyle of the tibia. The patella is located on the anterior part of the lower end of the femur. In complete extension of the knee it rests on the patellar articular surface on the anterior aspect of the femur. In extension it glides over the lower end of the femur, coming to lie on a part of the inferior articular surface in front of the intercondyloid notch. At complete extension of the knee, it is quite prominent, becoming less so as the knee is flexed.

The medial aspect of the region of the knee is formed by the medial condyles of the femur and tibia which are larger and more prominent than the lateral condyles. The lateral aspect is formed by the lateral condyles and the upper end of the fibula. The joint between the tibia and femur is located below the most prominent and bulging part of the knee. By careful palpation it may be felt as a faint but distinct groove on both the medial and lateral aspects. With the knee completely extended the joint will be located from

decreases in size from above downward to the junction of the middle and lower thirds of the shaft, expanding again at the lower extremity. Except for the expanded extremities, the fibula is of uniform size throughout. The bones of the leg are not in the same transverse plane. The proximal tibiofibular articulation is at the postero-lateral angle of the expanded upper end of the tibia. In the middle of the leg the shaft of the fibula is in a position distinctly posterior to that of the shaft of the tibia. Toward the ankle the fibula inclines forward so that at the joint it lies directly lateral to the tibia (Fig. 70).

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The medial aspect of the region of the knee is formed by the medial condyles of the femur and tibia which are larger and more prominent than the lateral condyles. The lateral aspect is formed by the lateral condyles and the upper end of the fibula. The joint between the tibia and femur is located below the most prominent and bulging part of the knee. By careful palpation it may be felt as a faint but distinct groove on both the medial and lateral aspects. With the knee completely extended the joint will be located from

¼ to ½ inch below the inferior end of the patella. To locate the joint with the knee flexed, the faint groove must be palpated.

Injuries of the bones around the knee joint are rather uncommon; infections of the joint and infections of or trauma to the numerous bursæ around the joint are probably more frequent than fractures. Of the bone injuries, fracture of the patella, separation of the lower epiphysis of the femur, and oblique fractures through the condyles of the tibia into the knee joint are probably most frequently encountered.

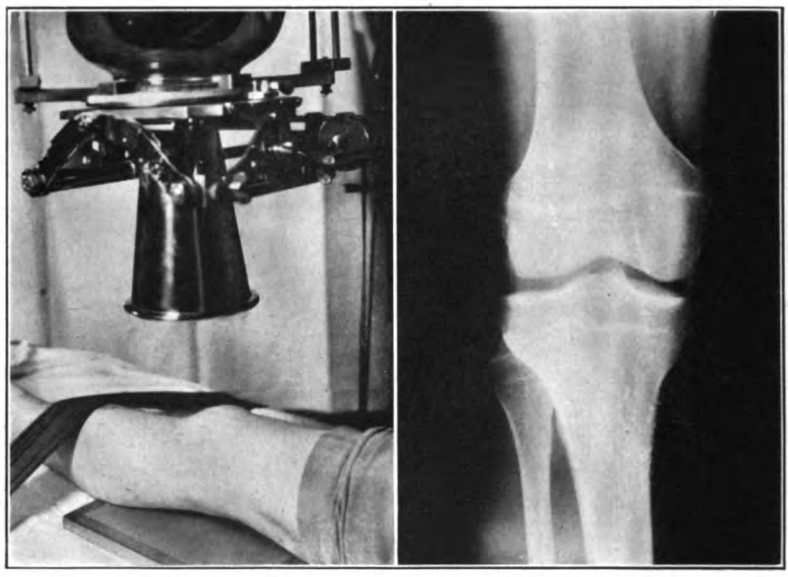

FIG. 74.—Antero-posterior exposure of the knee.

Roentgenography of the region of the knee includes exposures of films in all four directions. Of these, giving views at right angles to each other, the antero-posterior and medio-lateral views are most often made. The antero-posterior view is made with the joint completely extended and lying on the cassette (Fig. 74). The joint should be at the middle of the film area used, so that the same length of bones of the leg and thigh will be included. If the knee is flexed and cannot be straightened, two views must be taken, one of the bone above and the other of that below the joint.

For the medio-lateral view the patient is turned to the lateral position, the lateral aspect of the knee placed against the cassette

and the joint kept extended as far as possible (Fig. 75). A small sand bag or other support under the heel will assist in maintaining the true lateral position. In this position the medial condyles should be directly over the lateral with the joint in the middle of the film area. To obtain this view it may be necessary to flex the opposite thigh and leg and bring them anterior to the extremity being examined. In doing this the flexed extremity may be supported with pillows. Care should be taken to see that the body is not rotated toward the prone position, thus rotating the knee and giving an oblique rather than a directly lateral view.

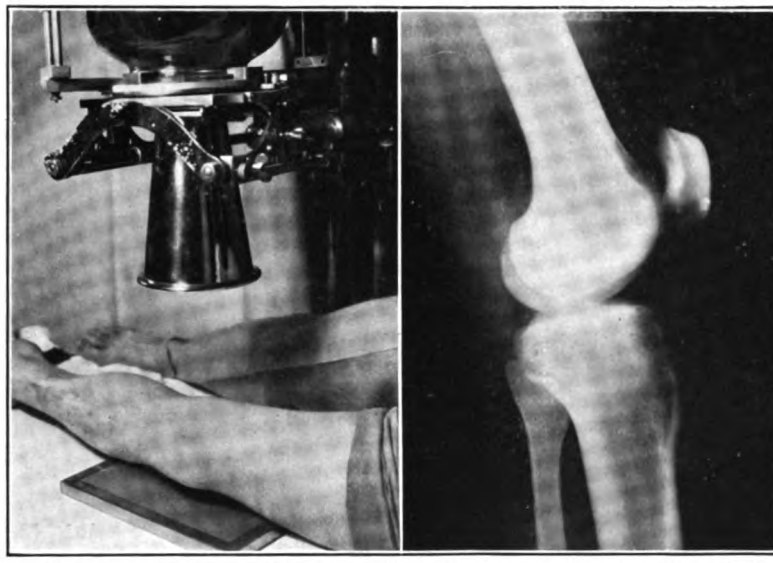

FIG. 75.—Lateral exposure of the knee. To maintain a true lateral position the heel must be elevated on a small sand bag.

Case recommends the postero-anterior rather than the antero-posterior as a routine position for examining the knee. It brings the patella nearest the cassette and is especially important in examining that bone. To obtain this view it may be necessary to support the thigh and leg on sand bags so that the patella is just off the cassette. For a latero-medial view the extremity may be placed on some support, the cassette placed along the medial aspect and the rays directed horizontally through the knee (see Fig. 77). The same view may be taken with the patient in the lateral position with the knee being examined uppermost, and it, with the cassette and

rest of the extremity, supported on a long, narrow, three-sided, box-like support.

To show all of the region of the knee in any position an area of film at least 5 by 10 inches in size must be used. This makes it possible to make the two views on a 10- by 12-inch film divided transversely or on two smaller films. The central ray should in each instance be focused directly over the joint space. Immobilization of both lower extremities with double sand bags is always advisable.

In investigating the region of the knee for slight injuries and especially for early infection, stereoscopic films give more information than plane films. For injuries, the tube shift should be across the long axes of the bones; for infections the shift should be longitudinally, across the epiphyseal lines or cartilages and the joint space, or views with the tube shift in both directions may be made on three films by the method described by Moore (page 181). Antero-posterior and lateral stereoscopic views of the same knee may be made on two 10- by 12-inch films divided transversely, using one-half of both films for each view.

THE THIGH.

The femur is the bone of the thigh. At its upper end it forms the hip joint; at its lower end it enters into the formation of the knee joint. It is the longest and strongest bone of the body. Its shaft is cylindrical, of uniform thickness throughout, and presents a distinct curve anteriorly. It is entirely surrounded by muscles and is palpable only at the extremities.

Fractures of the shaft of the femur are rather common injuries. They are most frequent through the middle third, next most frequent through the upper third in the subtrochanteric region, and least frequent through the lower part. Before treatment, the separation of fragments, overlapping, and deformity of any fracture of the femur may be quite marked. The most common displacement of the broken ends of the bone is in the antero-posterior plane, the upper fragment being displaced forward and lateralward, and the lower fragment backward and medialward.

Roentgenograms of the shaft of the femur should be made in both the antero-posterior and lateral positions. The antero-posterior view is made by placing the cassette in contact with the posterior aspect of the thigh (Fig. 76). In cases of injury it is too painful to turn the patient to the lateral position for the lateral view. This

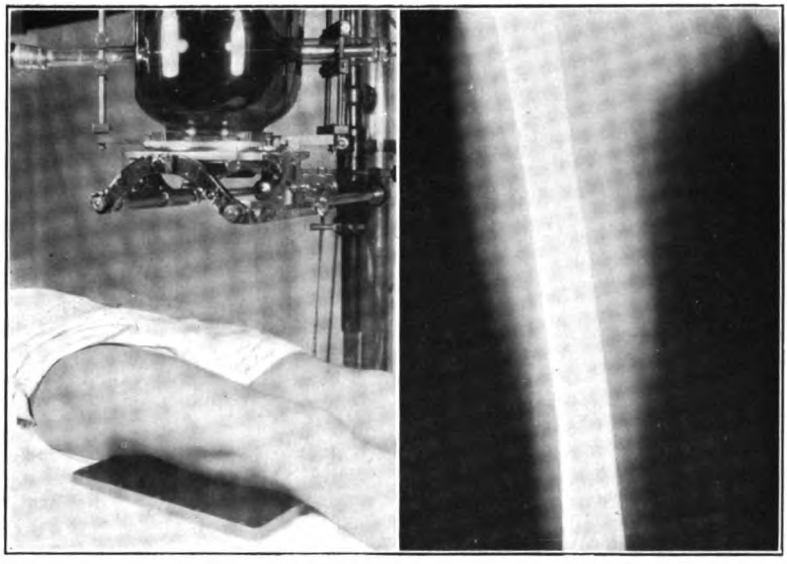

FIG. 76.—Antero-posterior exposure of the thigh.

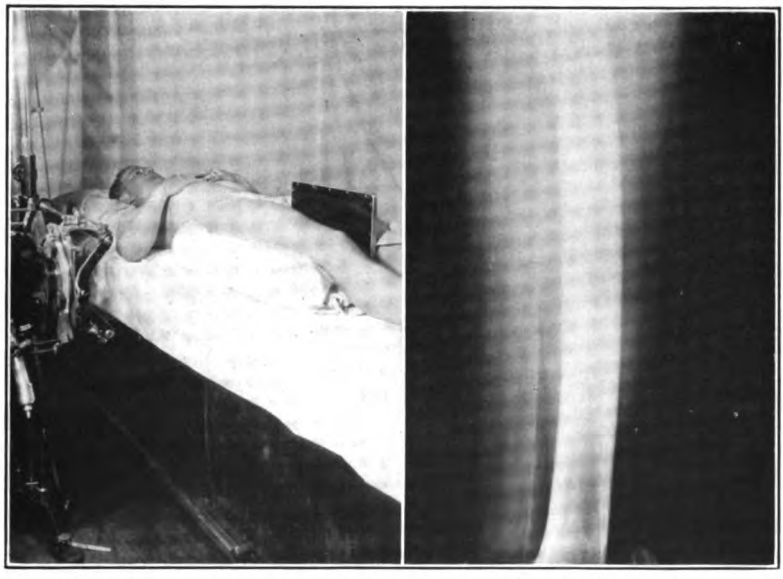

FIG. 77.—Lateral exposure of the thigh made by standing the film on edge with the rays directed horizontally. With a fracture of the shaft of the femur this method of lateral exposure is preferable to turning the patient to the lateral position. A similar procedure may also be used for lateral exposures of the ankle, leg, and knee.

view should, therefore, always be made by standing the cassette on edge along the medial aspect and directing the rays horizontally through the thigh (Fig. 77). Occasionally the patient is brought for examination with the injured thigh in the lateral position. It is then necessary to make the antero-posterior view with the vertically placed film and horizontally directed rays and the lateral view with the perpendicularly directed rays. Since the most common displacement is in the antero-posterior plane, the lateral view should never be omitted.

The size of the film will depend on the accuracy of the location of the injury. A 10- by 12- or 11- by 14-inch film divided in either direction or two 8- by 10-inch films should be used. The central rays should be directed as nearly as possible through the site of the injury. Many injuries and infections of the shaft of the femur extend upward so as to involve the region immediately below the trochanters. Films of these should be taken in the antero-posterior direction and stereoscopically as given under the examination of the hip. Even if the film for the lateral view placed as high in the crotch as possible does not include all of the injured area, the lateral view will show displacements more distinctly than the stereoscopic films and should be taken.

THE HIP.

The region of the hip is made up of the upper extremity of the femur with the acetabular cavity and adjacent parts of the hip bone. The upper end of the shaft is somewhat expanded at its attachment to the neck of the femur. Projecting backward and upward from its upper end is the large greater trochanter. The lesser trochanter is attached at the level of the lower margin of the neck and extends medially and backward. Connecting the two trochanters on the posterior aspect is the prominent intertrochanteric crest; on the anterior aspect is the much less prominent intertrochanteric line. The neck of the femur is a stout mass of bone slightly compressed antero-posteriorly, extending upward and mesialward at an angle of 120 degrees or more with the shaft. The head of the femur is spherical in shape and is attached to the end of the neck.

The acetabulum is a wide deep cavity on the outer aspect of the hip bone. It is surrounded by a prominent margin, especially above and behind. In the lower part there is a deficiency called the acetabular notch. In the acetabulum there is a horseshoe-shaped articular surface for articulation with the head of the femur. The acetabulum is developed in three parts, one each from the pubis,

ischium, and ilium. In early life these three parts are separated by cartilage. Bony union is completed about the twentieth year.

The hip joint is of the ball-and-socket variety permitting movements in several directions. Flexion and extension, abduction and adduction, and medial and lateral rotation are all represented. The most important of these to the technician is the rotation around a vertical axis. This is said to be through an arc of 45 degrees, about one-half as much as is permitted at the shoulder joint.

Since most of the upper extremity of the femur and all of the hip joint are rather deeply placed and not palpable from the exterior, it is important that the methods of locating the hip joint be thoroughly understood. The palpable bony points upon which this depends are the anterior superior iliac spine, the upper border of the symphysis pubis and the pubic spine, and the greater trochanter of the femur. The anterior superior iliac spine is found at the anterior end of the crest of the ilium. The crest and anterior spine can always be palpated even in persons who are very obese.

The upper border of the pubis is also always palpable. It terminates laterally at the beginning of the inguinal ligament in the pubic tubercle. The tubercle is only palpable in those who are rather slender. The greater trochanter is rather prominent in those who are slender but it is located at the bottom of a slight depression in those who are at all fat. With the muscles of the thigh relaxed the outer surface of the greater trochanter, especially the upper and posterior part, can be palpated.

The hip joint is located in the middle of a line connecting the upper part of the greater trochanter of the femur with the tubercle of the pubis. Its position in a supero-inferior direction can always be located by determining the level of the trochanter, the pubic tubercle, or the upper border of the pubic bones. For the position in the opposite direction the mid-point between the pubic tubercle and greater trochanter may be taken. One of the ways that has been used in locating the hip joint is for the operator to stand at the side of the patient, place the hand corresponding to the side being examined, with the middle finger on the top of the greater trochanter, the thumb on the anterior superior iliac spine, and the index finger over the front of the hip completing the tripod, the distance between the digits being equal. With the hand in this position the index finger will be directly over the hip joint.

From the acetabular cavity the neck of the femur extends lateralward, usually with an inclination backward. The position of the

neck may be determined by the position of the foot, or preferably by determining the position of the lower extremity of the femur. If the foot is neither inverted nor everted, the long axis of the foot is approximately at a right angle to that of the neck of the femur. The neck of the femur is directed 12 degrees anterior to a line connecting the two epicondyles at the lower extremity of the femur, so that it may be stated that the neck of the femur is directed in approximately the same plane with the epicondyles.

Fractures of the upper extremity of the femur are quite common. The neck may be fractured through any part; it may be driven into the greater trochanter causing more or less splintering, usually with some impaction, or there may be fractures below the trochanters, involving the upper part of the shaft. Dislocations of the hip joint are rather rare in a roentgenological practice. Infections of the upper end of the femur and hip joint, both tuberculous and non-tuberculous, are also quite common.

Lateral roentgenograms of the hip are so difficult to make satisfactorily that they are usually not attempted, dependence being placed on antero-posterior views. Whenever possible, these should be made stereoscopically with the aid of a Potter-Bucky diaphragm.

For such an examination the Roentgen-ray tube is centered over the diaphragm and arranged so that the tube shift is to be across the upper end of the femur and across the grid strips. The patient is placed with the hip to be examined over the center of the diaphragm or slightly above it, the location of the joint being determined by the method outlined in a preceding paragraph. Whenever possible, the lower extremity is arranged so that the neck of the femur extends laterally from the joint. This position will be obtained when the condyles of the femur are both in the horizontal plane or when the foot is in a position of slight inversion. The extremity should be held in this position with sand bags (Fig. 78). Films made with the foot everted and the extremity rotated lateralward show the neck of the femur obliquely and are not as valuable as those on which the neck is shown in profile.

By carefully placing the patient, the hip joint may be taken stereoscopically on two 8- by 10-inch films. It is better, however, to use two 10- by 12- or 11- by 14-inch films. It should be remembered that stereoscopic films made with the tube shift across the grid strips require 25 per cent more exposure than films made with the tube in the center or shifted lengthwise with the strips (page 148).

When the Potter-Bucky diaphragm is not available or cannot be used, postero-anterior stereoscopic films should be made. When immobilization can be secured, it is best to use a long exposure with a low voltage and a small cone or diaphragm. For this purpose the 10- by 12-inch size of film is large enough. If stereoscopic films cannot be made, then single films will have to be relied upon. In making interpretations of any but stereoscopic films caution should be exercised in describing any deformity that may appear to be present.

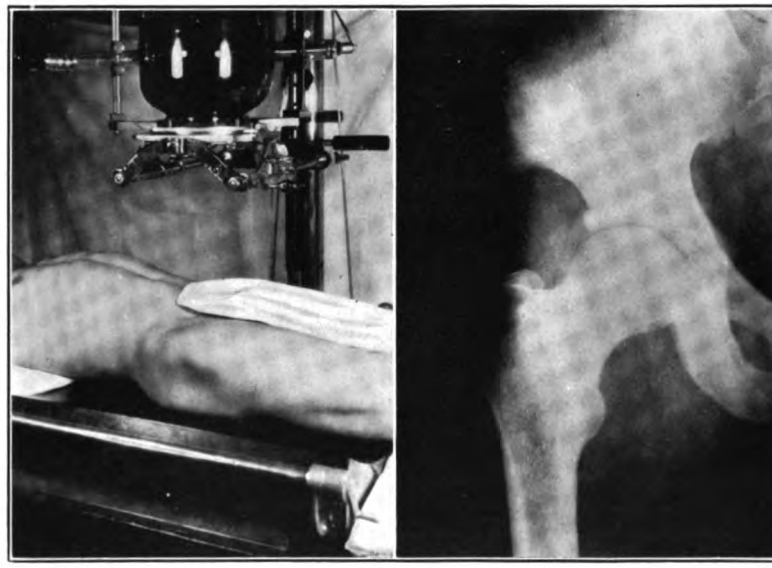

FIG. 78.—Antero-posterior exposure of the hip. To show the head and neck of the femur in profile, the toes must be directed upward or the foot slightly inverted.

Many attempts have been made to devise methods of making lateral films of the upper end and neck of the femur. Hickey has described a method that may be used with patients that can be turned on the affected side. The patient lies on the side to be examined, with the hip flexed so that the thigh forms a right angle with the long axis of the trunk. It is held in this position by sand bags. The opposite lower extremity is more or less extended and supported on pillows. The trunk may be tilted backward, so that the thigh is in a position of abduction as well as flexion, and the back supported with pillows or sand bags. The cassette is placed under the greater trochanter of the side being examined. The

central rays from the tube are directed from above downward at an angle of 20 to 25 degrees in front of the trunk, emerging through the greater trochanter. This position was described before the invention of the Potter-Bucky diaphragm, but it may be adapted to that apparatus, especially one with a flat top.

Béclère and Porcher describe seven methods, some of them credited to other writers, for making lateral views of the upper end of the femur. The one that is considered best is attributed to Costes. The patient lies in the supine position with the film on edge between the thighs and pushed as far as possible into the perineum. The tube is turned horizontally with the rays parallel to the table top. The central rays are directed downward and medially toward the film, entering the side being examined a little above the wing of the ilium. In another method, attributed to Arcelin, the normal hip is flexed at an angle of 90 degrees, the film placed on edge along the side of the hip to be examined, the tube turned horizontally, and the rays directed slightly upward from the opposite side with the central rays passing just beneath the perineum.

For one not equipped to make stereoscopic films, a film exposed by either of these methods might give information of value concerning antero-posterior displacements in fractures of the upper end of the femur.

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CHAPTER XIV.

THE VERTEBRAL COLUMN, THORAX, AND PELVIS.

THE VERTEBRAL COLUMN.

THE vertebral column is made up of the twenty-four movable vertebræ and the fixed vertebræ in the sacrum and coccyx. The movable are divided into seven cervical, twelve thoracic, and five lumbar. Except the first and second cervical which are atypical, each vertebra has the same parts. The body, directed forward, is a mass of bone shaped like a short segment of a flattened cylinder. The body supports the vertebral arch behind, which consists of the roots of the vertebral arches (pedicles) and the laminæ. From the sides of the body and from the vertebral arch there spring seven processes. Two of these, the transverse processes, are directed lateralward; one, the spinous process, extends either directly or obliquely posteriorly; and the other four, the articular processes, are directed, two upward and two downward, for articulation with similar processes of the vertebræ above and below (Fig. 79).

With the exception of the upper thoracic, the bodies of the vertebræ gradually increase in size from the second cervical to the fifth lumbar. In the cervical region the spinous processes are directed nearly horizontally and are bifid at the tip. Those of the thoracic vertebræ have more of an inclination downward. This increases from the first to the eighth, then decreases rapidly so that the twelfth is nearly horizontal. Those of the lumbar region are quadrilateral and directed horizontally backward. The spaces between the spinous processes are greatest in the lumbar region. A slight lateral inclination of one or more of the spinous processes is not unusual and must not be mistaken for injury. The transverse processes partly spring from the sides of the bodies in the cervical and from the vertebral arch in the other regions. They have a distinct posterior inclination on the thoracic vertebræ, but are directed more nearly transversely in the cervical and lumbar regions. They are most prominent in the upper thoracic and in the lumbar regions. The articular surfaces of the articular processes are placed

in a transverse plane in the cervical and thoracic, gradually changing to an antero-posterior direction in the lumbar region.

The vertebral column presents distinct curves in the antero-posterior direction. The curve extends forward in the neck, backward in the thorax, and forward again in the lumbar vertebræ (Fig. 80, B). A slight lateral curvature is also found so often that it may be considered a normal finding. The convexity of this curve is usually to the right at about the fourth thoracic vertebra.

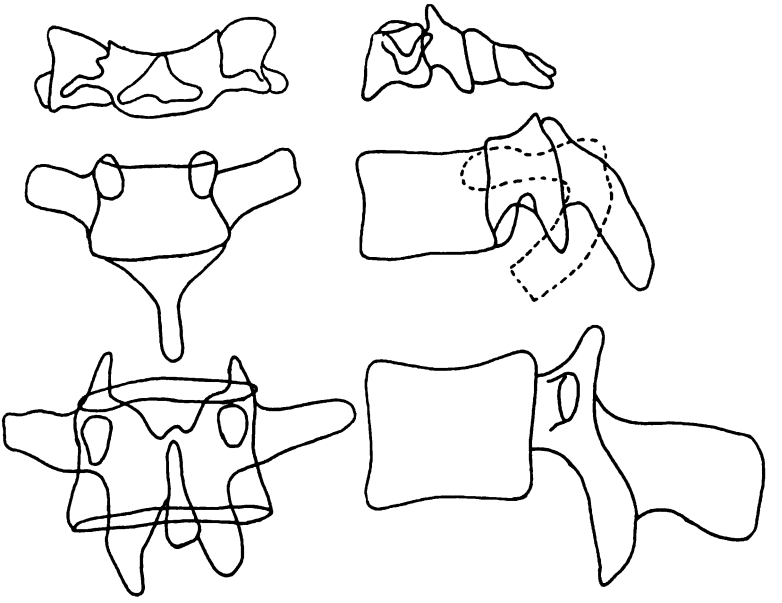

FIG. 79.—Outline tracings of the fourth cervical, seventh thoracic, and fourth lumbar vertebræ as they appear on antero-posterior and lateral roentgenograms.

The sacral and coccygeal vertebræ, five and four in number respectively, in the adult are fused into two bones. The sacrum is triangular in shape, widest at the superior part, rapidly tapering inferiorly. It joins with the fifth lumbar vertebra at a distinct angle with a prominence, the promontory, projecting anteriorly. It is rather obliquely placed, with a marked posterior curve. On the sides of its lateral masses it has large, rough, articular surfaces for articulation with the ilii to complete the pelvis posteriorly. The coccyx is much smaller and is composed of four rudimentary segments of which the upper is the largest and the lower the smallest. After middle life it frequently fuses with the sacrum.

Injuries of the vertebral column, while not common are becoming more frequent because of the increase in the number of severe injuries due to automobile accidents. The usual type consists of a compression fracture of one or more of the bodies of the vertebræ from hyperflexion of the spine. These may be complicated by fractures of the transverse processes or other small parts of the bones. Such injuries are most frequent at the junction of the more movable with the less movable portions of the column. Thus, fractures of the first lumbar vertebra and of the ones on each side of it are more common than all other spine injuries combined. Wallace found that 70 per cent of 82 instances of spine injury were to the bodies of the twelfth thoracic and first two lumbar vertebræ.

Dislocations of the vertebræ are rather rare. The cervical region is the most common site. The usual form is a dislocation forward of a vertebra on the one below, often accompanied by fractures of some of the processes. More or less displacement of the vertebræ is present in the more severe injuries in other localities.

Diseases of the bodies or other parts of the vertebræ are rather rare lesions. They are most often a tuberculous infection or metastases from a distant malignancy. Pain in the back, usually in the lumbar portion, is a frequent symptom that calls for Roentgen-ray examination of the vertebral column. Congenital anamolies occur most frequently in the lumbosacral region, involving the first piece of the sacrum or the fifth lumbar vertebra, and are probably a cause of symptoms referred to the lower part of the back.

The extent of the vertebral column and the depth at which it is placed makes the exact location of a particular segment often a difficult procedure. To assist in placing patients and films for Roentgen-ray examination of the spine, a number of landmarks which give the approximate location of certain vertebræ may be used. These are given below, taken mostly from Rawling. While there is probably some variation in the exact location of the vertebræ, depending on body habitus, those given are adequate for the purpose for which they are here intended (Fig. 80, A).

First cervical—Level of the hard palate.

Second cervical—Level of the free margin of the upper teeth.

Second to third cervical—Level of the hyoid bone.

Fourth cervical—Level of the upper part of the thyroid cartilage.

Sixth cervical—Level of the cricoid cartilage.

Disk between the second and third thoracic—Suprasternal notch.

Disk between fourth and fifth thoracic—Junction of manubrium and body of sternum.

Disk between ninth and tenth thoracic—Sternoxiphoid junction.

First lumbar—Transpyloric plane, midway between umbilicus and sternoxiphoid junction.

Disk between third and fourth lumbar—Umbilicus.

Fifth lumbar—Plane connecting anterior superior iliac spines.

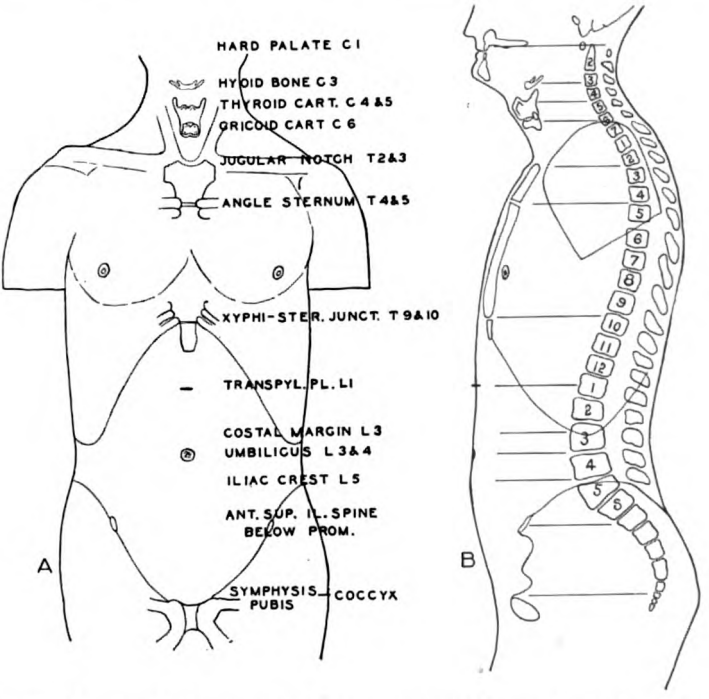

FIG. 80.—Landmarks for exposing different parts of the vertebral column: A, for antero-posterior exposures; B, for lateral exposures. The letters C, T, and L, followed by numbers refer to particular cervical, thoracic, and lumbar vertebræ.

In addition to the above landmarks, with the patient in the lateral position there are a few others that are useful. The transverse process of the atlas can be palpated by deep pressure just below and in front of the tip of the mastoid process; the most prominent spinous process at the root of the neck posteriorly is that of the seventh cervical vertebra; the lower border of the lateral part of the costal margin is usually opposite the third lumbar vertebra; a line connecting the highest point of the iliac crests, which can be

determined by palpation, crosses the body of the fourth lumbar vertebra, and the lumbosacral junction is about 1½ inches below the highest point of the iliac crest and about midway from anterior to posterior on the lateral aspect of the ilium (Fig. 80, B).

Roentgenograms of the vertebral column are most often made in the antero-posterior and lateral directions and less often in an oblique direction. Since the most common injury is one of crushing of the body that is shown better on lateral than antero-posterior films, lateral views should always be taken. Hickey, Bowman, Brailsford, and Balensweig all emphasize the importance of lateral views, the last named two even stating that a lateral view is of more importance than an antero-posterior one. In antero-posterior views images of the different parts of each vertebra are more or less superimposed. Thus the shadows of the body, the roots of the vertebral arches, the laminæ, the spinous processes, and, to a less extent, those of the articular processes, may be in the same area. Only the transverse processes project lateralward to the sides of the images of the other parts, and in certain regions parts of the images of the laminæ, the articular and the spinous processes, project across the shadows of the intervertebral disks (Fig. 79).

In lateral views the outlines of the bodies and spinous processes are seen in profile, but those of other parts are superimposed so that differentiation of those of opposite sides is impossible (Fig. 79). Oblique views are taken usually for special purposes, but they, too, show a superimposition of shadows of some parts of the bones.

Throughout most of the vertebral column, roentgenography is complicated by the presence of other structures that are radiopaque and cast shadows on the films. The mandible in the upper cervical region, the sternum, ribs, heart and aorta, the pectoral girdle and shoulders in the thoracic region, and the lower ribs and the alæ of the ilii in the lumbar region complicate both the exposure and interpretation of films of the vertebral column.

Roentgenography of the vertebral column is further complicated by distortion in shape of the bodies and other parts of the bones. This is especially true if any considerable portion of the spine is included on a large film. Those bodies in the center of the film, in the path of the central rays, will be shown in nearly their exact size and shape. The rays will pass directly through the intervertebral spaces showing them as clear zones on the films. Other vertebræ, either above or below the center, will be increasingly distorted as they are removed from the path of the central rays; the

intervertebral spaces will be overlapped by the images of the bodies, and there will be overlapping of the images of other structures. In the cervical and lumbar regions the presence of the anterior curvature makes distortion in shape more pronounced than it is on films of the thoracic region where the curvature is posterior.

The anatomical peculiarities and the difficulties encountered in roentgenography of the spine enumerated above indicate certain general principles that should be observed in making Roentgen-ray examinations of any part of the vertebral column. The complexity of the structure of the vertebræ makes necessary the use of stereoscopic films, at least in the antero-posterior direction, so that the perspective afforded by them will enable the examiner to look in front of and through the images of certain parts to examine the others. The superimposition of the shadows of other opaque structures on those of the vertebræ is an additional factor favoring the use of stereoscopic films and the employment of various positions to obtain films the images on which are as nearly as possible free from such shadows. The greater frequency of injury and disease of the bodies requires the exposure of lateral films so that these parts may be seen in profile and compared one with another. The distortion in size and shape, especially when large films are used, suggests that it is better to make examinations on relatively small films, including only a small area on each, and, if the examination of a large extent of the column is necessary, exposing more than one set of films.

THE CERVICAL VERTEBRÆ.

Because of the presence of the mandible, antero-posterior films of the cervical vertebræ cannot all be taken at one time. George described a method of making such views of the first two through the open mouth. The patient is placed on the table in the supine position without a pillow. The head is adjusted until a line from the edges of the upper incisor teeth to the tip of the mastoid process is perpendicular to the table (Fig. 81). The cassette is placed under the head, with the external occipital protuberance on its upper margin. The mouth is opened as far as possible and held open by placing a large cork between the teeth. The central rays are directed perpendicularly to the film through the center of the open mouth. Immobilization of the head with a double sand bag across the forehead and suspension of respiration during the exposure are necessary.

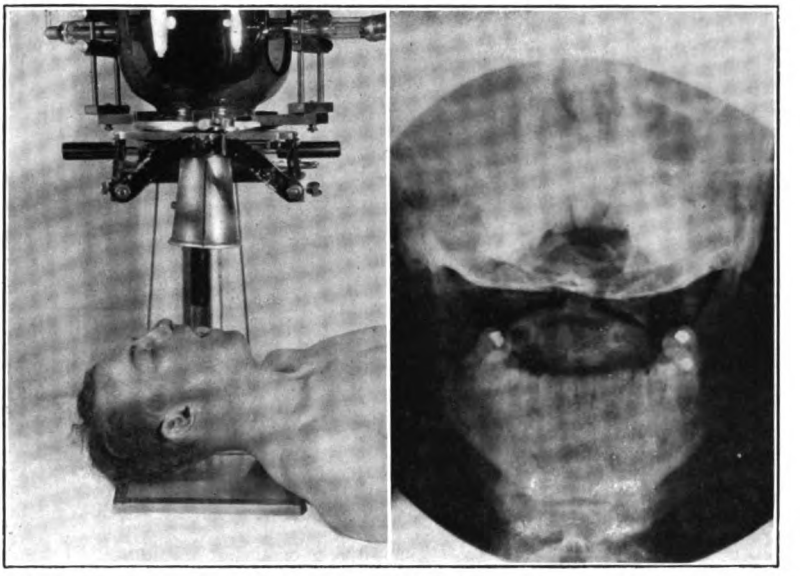

FIG. 81.—Antero-posterior exposure of the first and second cervical vertebræ through the open mouth. The mouth is held open by a large cork; a line from the edge of the upper incisor teeth to the tip of the mastoid is perpendicular to the cassette.

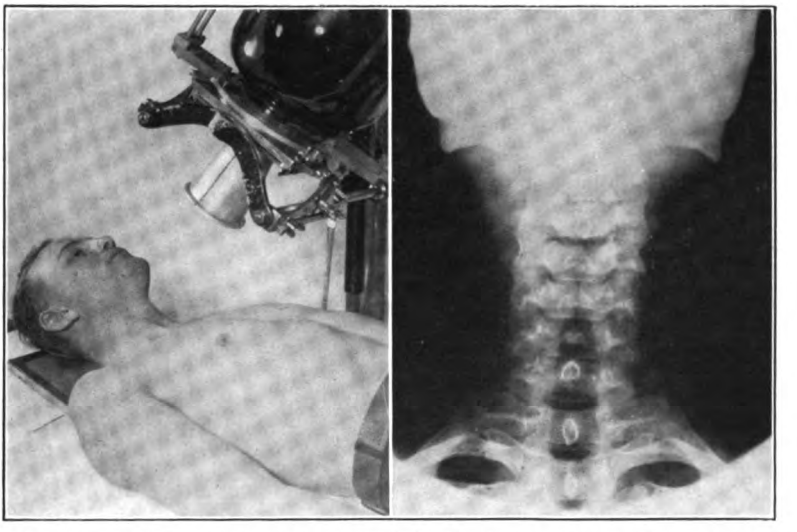

FIG. 82.—Antero-posterior exposure of the lower cervical vertebræ. In this instance the lower six are shown. The top of the cassette is elevated on a sand bag, the chin is extended, the tube is tilted toward the head, and centered over the most prominent part of the larynx.

The smaller films, either the 5- by 7- or 6½- by 8½-inch size, are large enough for this exposure.

For antero-posterior views of the lower cervical vertebræ, to straighten out the anterior curve as much as possible, the upper border of the cassette or plate-changing tunnel is elevated with an inclined block or with a sand bag, the upper border of the film being as high as the external occipital protuberance (Fig. 82). The chin is elevated as much as possible and the head immobilized with a double sand bag. The tube is tilted so that the rays strike the film perpendicularly or are directed slightly obliquely upward. The central ray is directed through the most prominent part of the larynx. Films of the 6½- by 8½-inch size will include all of the lower cervical vertebræ and the upper one or two thoracic vertebræ as well. Suspension of respiration during exposures is necessary.

Lateral views of the cervical spine present the same difficulty as do the antero-posterior views except that the trouble comes from overlapping of the lower cervical vertebræ by the shoulders. By placing a patient in the lateral position with the head supported on a block or pillow and the cassette under the neck, pushed as far down against the shoulder as possible, lateral views of the upper cervical region can be secured. A procedure for exposing lateral films which will show all of the cervical vertebræ and the first thoracic in the lateral projection is the one recommended by Grandy.

The essential features of this method are the placing of the film, not along the side of the neck, but parallel with the neck at the side of the shoulder, and using an anode-film distance of 5 feet or more. Such exposures may be made either with the patient sitting or in the supine position. In the sitting posture the patient is seated at the side of a cassette-holding device with the head erect and supported by a headrest fastened to the back of the chair. The shoulder is pressed firmly against the cassette holder and both shoulders are depressed as much as possible. In the supine position the patient lies on the table with a flat, non-radiopaque pillow placed lengthwise under the head, neck, and shoulders (Fig. 83). The cassette, standing on edge and either held or supported in position, is placed along the side of the shoulder and parallel with the neck. The shoulders are depressed as much as possible by having the patient reach downward with the upper extremities at the sides of the trunk.

In either case the Roentgen-ray tube is turned horizontally, the central rays being directed toward a point halfway between the

pinna and the shoulder. An anode-film distance of 5 to 7 feet is required. A 10- by 12-inch film should be used, with its long axis parallel with the neck and its upper border above the pinna. Suspension of respiration is not required, but the patient should be instructed to lie or sit still and breathe quietly. The time of the exposure may be calculated according to the instructions given under Experiment 5 on page 110.

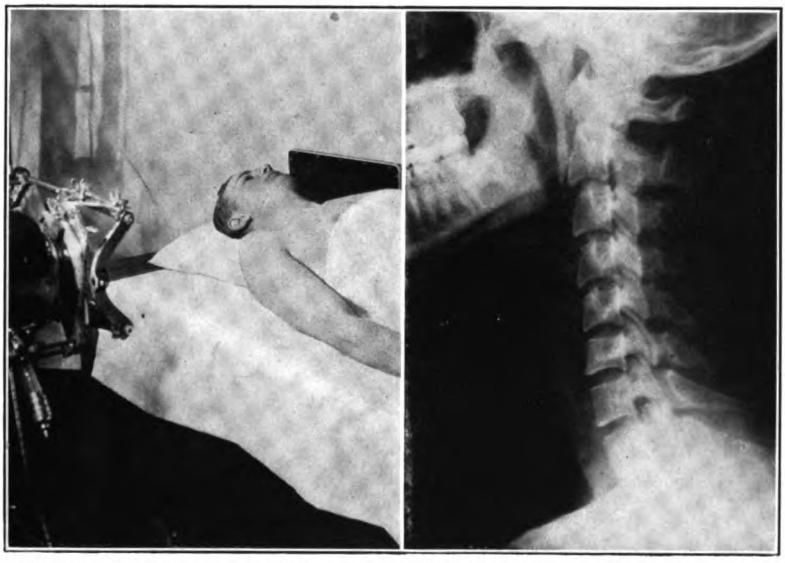

FIG. 83.—Lateral exposure of the cervical and first thoracic vertebræ. The cassette is placed parallel with the neck and along the shoulder; the shoulders are depressed as much as possible; the anode-film distance is 5 feet.

THE THORACIC VERTEBRÆ.

Films of the thoracic vertebræ may be taken in the antero-posterior, the oblique, and all but the second and third in the directly transverse direction. The antero-posterior films should present no special difficulty. They should always be taken stereoscopically and with the use of the Potter-Bucky diaphragm (Fig. 84). The tube is placed directly over the center of the diaphragm and moved to one side until the patient has been placed. The suspected region of the vertebral column is placed over the center of the diaphragm so that it will fall near the center of the films. The first film is put in place and the tube moved first back to the center position and then $1\frac{1}{4}$ inches from the center position.

The patient should suspend respiration during the exposure and remain immobile while the film is being changed and the tube moved for the second exposure. The second is made with the tube $2\frac{1}{2}$ inches from its position during the first exposure, the shift being in the long axis of the column.

For the oblique position, the patient lies on the Potter-Bucky diaphragm with the left side of the back in contact with the top of the diaphragm and the body rotated at approximately the halfway position between the supine and left lateral positions. The left shoulder and upper extremity are brought forward and the right

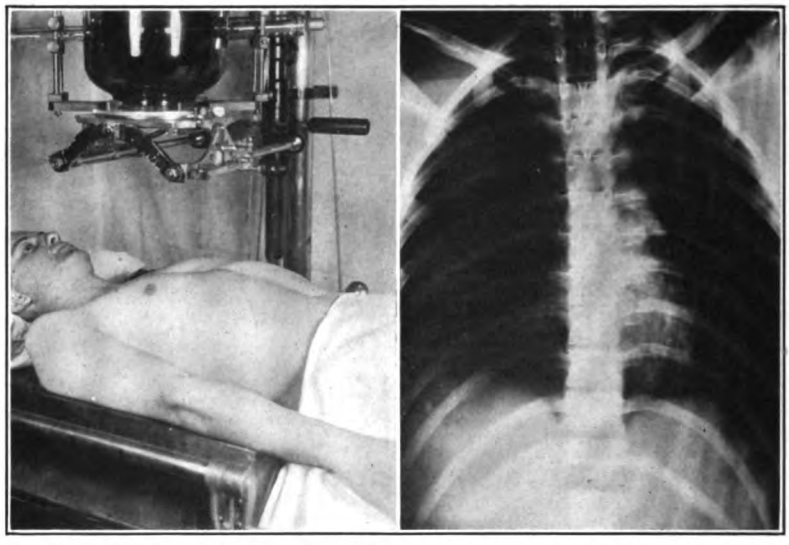

FIG. 84.—Antero-posterior exposure of the thoracic vertebræ. The tube is centered just below the angle of the sternum.

upper extremity carried upward across the head. Immobilization is secured by means of pillows, sand bags, and the compression band of the diaphragm. Suspension of respiration is essential. The size of the film will depend on the extent of the column being examined, but it should not be smaller than the 10- by 12-inch size. Stereoscopic films in this position may be made by following the instructions given above and on page 180.

Lateral films are made by placing the patient on the Potter-Bucky diaphragm in the lateral position, with both arms above the head (Fig. 85). Immobilization, suspension of respiration, the size of

the film, etc., are the same as for the oblique views. An anode-film distance of 30 or 35 inches is advisable. If a slightly higher voltage or longer exposure than is required for the cervical vertebræ is used, a true lateral view of the first thoracic vertebra may be made according to the method devised by Grandy and described above for a lateral view of the cervical vertebræ (Fig. 83).

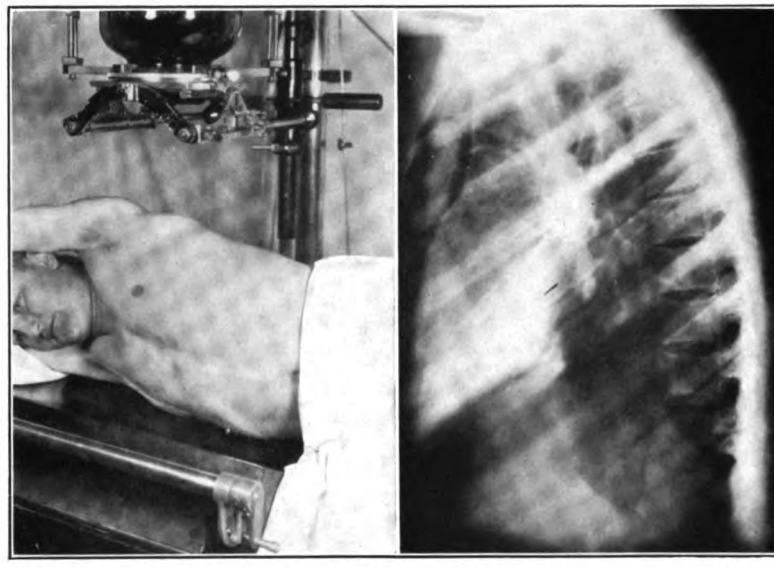

FIG. 85.—Lateral exposure of the thoracic vertebræ. The upper two thoracic vertebræ cannot be shown on this view. A similar position may be used for lateral exposures of the thorax.

THE LUMBAR VERTEBRÆ.

Roentgenograms of the lumbar vertebræ should be made stereoscopically in the antero-posterior direction and in the transverse direction, using the Potter-Bucky diaphragm for both exposures. Because the convexity of the curvature of the lumbar spine is anterior, in antero-posterior views distortion in shape is often quite marked (Fig. 86). If precautions are taken to straighten the spine as much as possible, this will be reduced to a minimum. The shoulders and head should be well supported, the upper extremities flexed across the chest, the compression band of the diaphragm should make firm pressure across the lower ribs and upper part of the abdomen, and in many instances it is advisable to flex the hips and knees and support them on pillows or a special device placed

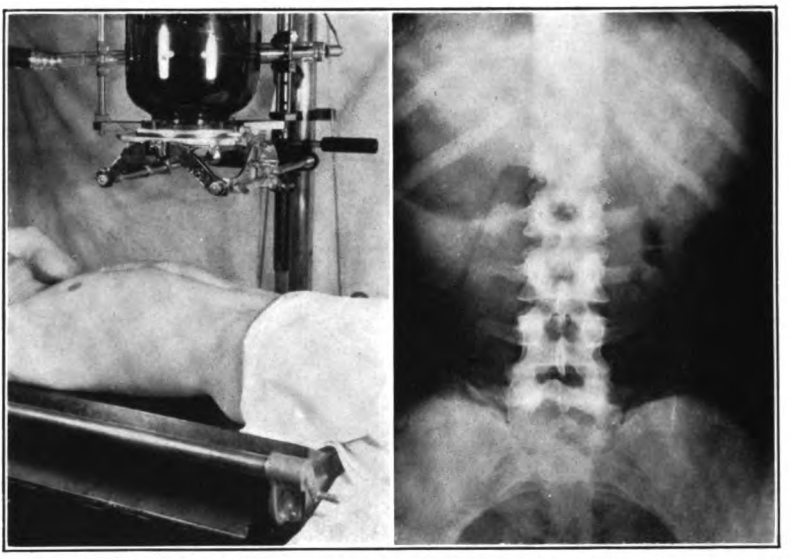

FIG. 86.—Antero-posterior exposure of the lumbar vertebræ. The tube is centered about 1 inch above the umbilicus. For undistorted images of the region of the first lumbar vertebra, the region where more than half of vertebral injuries occur, the tube should be centered halfway between the sternoxiphoid junction and the umbilicus.

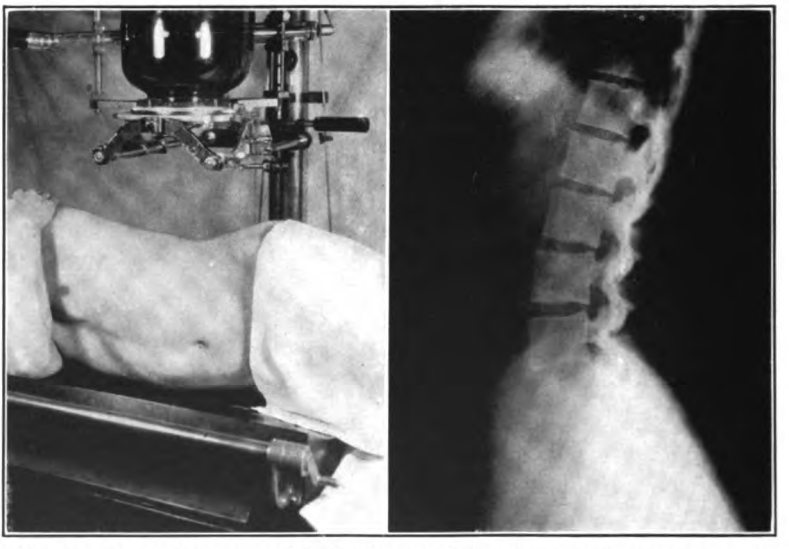

FIG. 87.—Lateral exposure of the lumbar vertebræ. The tube is centered over the lower costal margin and tilted, usually toward the feet, so that the rays will pass between the vertebral bodies.

beneath the knees. An anode-film distance of 30 or 35 inches will also reduce distortion.

Distortion in lateral views will also be present unless the tube is placed so that the rays pass directly through the intervertebral spaces parallel with the margins of the bodies of the vertebræ. In the lateral position the pelvis is thicker than the trunk through the lumbar region, which causes a lateral bend in the lumbar spine. The tube should be tilted at a small angle, usually toward the feet, to compensate for this curvature. Jerman suggests that a line be drawn with a skin pencil from the lumbosacral junction to the tip of the spinous process of the first lumbar vertebra and the rays directed perpendicularly to this line. An anode-film distance of 30 or 35 inches will also decrease distortion (Fig. 87).

In patients with suspected spine injuries particular attention should be paid to the region of the first lumbar and adjacent vertebræ. For this region the position of the tube to the novice will appear unusually high; it should be centered over a point halfway between the umbilicus and sternoxyphoid junction. In the lateral position the tube should be centered about 2 inches above the lower costal margin (Fig. 80).

For views showing all of the lumbar spine the tube should be centered about 1 inch above the umbilicus for the antero-posterior views and over the lower costal margin for transverse views (Figs. 86 and 87). For the lower lumbar and lumbosacral region the tube should be centered on a line connecting the highest points of the iliac crests. This is called the intertubercular line. If the lumbosacral region is to be shown in transverse direction, the tube should be centered over the ilium on a line with the anterior superior iliac spines. In exposing this region in the lateral position the rays must pass through the hip bones on both sides and through the width of the sacrum, making it one of the longest exposures in all roentgenography (see page 149).

THE RIBS.

There are twelve ribs on each side. The upper seven of these articulate with the thoracic vertebræ behind, and, by means of their costal cartilages, with the sternum in front. The next three are attached to the vertebræ but their cartilages extend upward to fuse with the cartilage of the rib next above. Thus the eighth unites with the seventh, the ninth with the eighth, etc. The lower two, the floating ribs, have a cartilage-tipped end which terminates in

the muscles of the side and back of the abdomen. The twelfth ribs may be rudimentary, even reduced to a small mass attached to the transverse process of the twelfth thoracic vertebra which may be mistaken for a renal stone. A more or less complete cervical rib may be present attached to the seventh cervical vertebra.

As they pass forward around the thorax all the ribs have an inclination downward. This increases from the first to the eighth or ninth and then decreases. The anterior end of the first rib is on the same horizontal level with the posterior end of the fourth. The ribs from the second to the sixth or seventh have their anterior ends on a level with the posterior ends of the fourth rib below.

The costal cartilages increase in length from the first to the seventh, then decrease, although the costochondral junction gradually inclines away from the midline from the second to the last. From the fourth downward, the cartilages have a distinct inclination upward, which increases from above downward.

The identification of a particular rib is often difficult. It can be done best by identifying a certain rib, then, if necessary, counting to the rib in question. The first rib is not palpable. The second lies on a level with the junction of the manubrium and body of the sternum. At this place there is a slight angulation forward in the sternum—the angle of the sternum—which forms a slight ridge transversely across the bone. The lower border of the pectoralis major muscle reaches to the fifth rib; the highest visible serration of the serratus anterior muscle is attached to the sixth rib; with the upper extremity at the side, the inferior angle of the scapula is over the seventh rib, and the lowest part of the inferior margin of the thorax is said to be formed by the tenth rib.

Fractures of ribs are not uncommon. Fractures of the first and second are rare. The ribs most commonly injured are in the middle, from the fifth to the ninth. The usual cause is direct violence, but compression of the thorax is also a cause. Fractures of the costal cartilages or their separation from the sternum or ribs are becoming more frequent from direct violence against the steering wheel in automobile accidents. The most common site for fractures in ribs is near the mid-axillary line.

The Roentgen-ray examination of the ribs for fractures does not present many difficulties. There are certain precautions, however, that must be observed. If the injury is due to a blow of any sort upon the chest, an examination of the injured region with films large enough to include the entire extent of the ribs under suspicion

is all that is required. If the violence has been such that the thorax is compressed, either anteroposteriorly or transversely, the ribs on both sides should be examined.

Roentgenograms of the ribs may be made either in the antero-posterior, the postero-anterior, or oblique directions. Since the anterior ends of the ribs are not well shown on antero-posterior views, if a single view is made, it should be in the postero-anterior direction (Fig. 88). In addition to such, oblique views should be made. For these, the patient is placed so that the region of the injury is against the cassette and the rays are directed perpen-

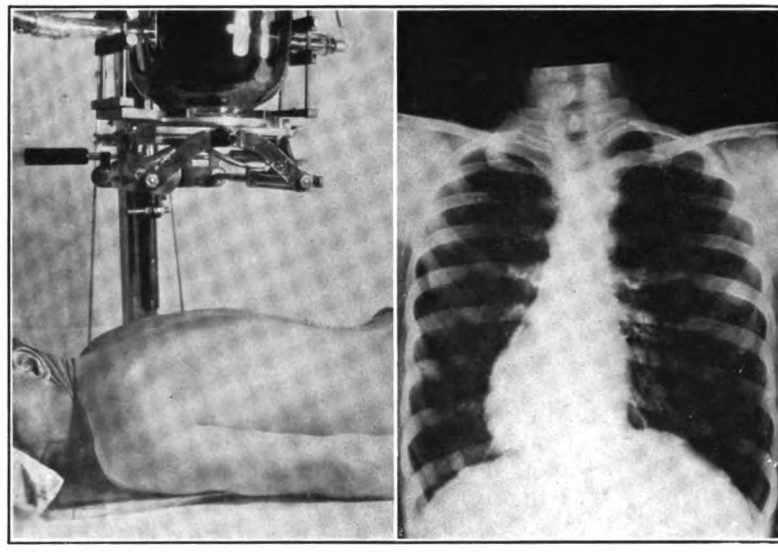

FIG. 88.—Postero-anterior exposure of the ribs. The shoulders are dropped forward so that the images of the scapulæ will not be over those of the ribs.

dicularly to the film through whatever aspect of the body the position of the patient requires (Fig. 89). For example, for fractures in the mid-axillary region, the patient is turned in a semilateral position and the rays directed toward the film either along the same or the opposite side of the vertebral column.

To show the middle and lower ribs in their entire extent, two films often are required. One of these is for the ribs above the level of the diaphragm, and the other for those below. The differences in the average density to Roentgen-rays of that part of the thorax occupied by the lungs and that part occupied by the liver and other

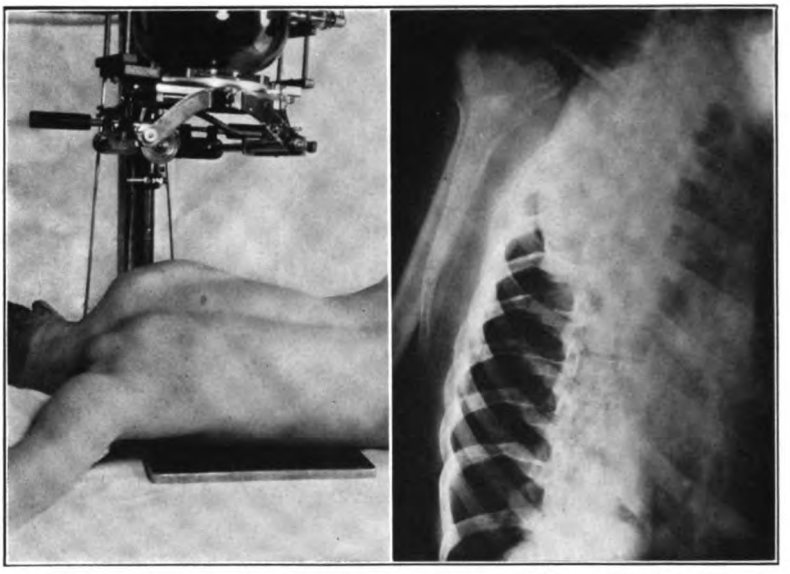

FIG. 89.—Postero-anterior oblique view of the right ribs. By placing the region of the suspected injury on the cassette and making an oblique exposure a film will be obtained that is often more informative than the direct postero-anterior projection.

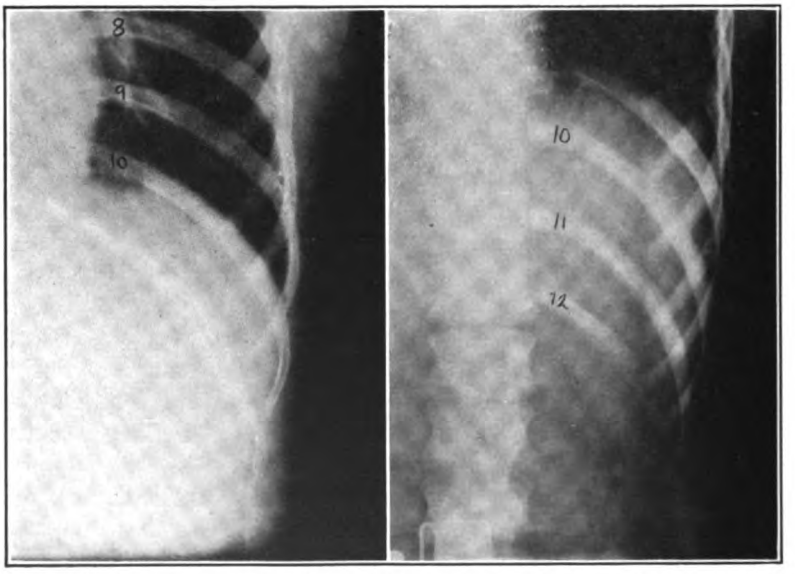

FIG. 90.—Exposures of ribs above and below the diaphragm. Those above the diaphragm are exposed at full inspiration using factors for the thorax through the lungs; those below the diaphragm are exposed at full expiration, using factors for the abdominal viscera or those for use with a Potter-Bucky diaphragm. Parts of some of the ribs will be clearly shown on both films.

abdominal viscera require a different technique for each part. In making exposures of ribs lying above the abdominal viscera the exposure is the same as for the lungs. To include as much of the ribs as possible on such films they should be made at the fullest inspiration. For exposures of the lower ribs, the technique for the abdominal viscera should be used. To include as much of the ribs as possible on such views, the exposures should be made during complete expiration. Parts of the same ribs will be shown on both films (Fig. 90).

The size of the films used in making exposures of the ribs depends entirely on the size of the region examined. Probably the 10- by 12-inch size is the smallest that should be used. For all of the ribs on one side of the body the 11- by 14-inch size is usually adequate. If all of the ribs are to be included, the 14- by 17-inch size is required. For small and medium-sized individuals the film may be used lengthwise, but for those that have a large and thick chest, it should be turned sidewise.

Suspension of respiration during exposures is, of course, necessary. Stereoscopic films will give more information than plane films, and are recommended. The Potter-Bucky diaphragm is required for those exposures made with the technique as for the abdominal viscera, and its use will improve the quality of films of the upper ribs. Stereoscopic films may be made with the diaphragm if the patient does not move between the exposures while the films are being changed and the tube shifted, and if the thorax is as nearly as possible in the same position, either in expiration or inspiration, when the films are exposed.

Unless rather densely calcified, costal cartilages will not be visible on Roentgen-ray films. Occasionally patients will be examined with enough calcium in the cartilages to enable a fracture to be detected. If lime salts are not present, cartilage injury or separation of the costochondral junction can only be suspected by the abnormal positions of the anterior ends of the ribs.

THE STERNUM.

The sternum, consisting of two bony portions, the manubrium and body, is located in the upper part of the anterior wall of the thorax in the midline of the body. It articulates with the clavicles above, with the cartilages of the upper seven ribs at the sides, and has the xiphoid (ensiform) process or cartilage attached to its lower

end. It is cancellous in structure with but little compact bone entering into its formation. Injuries and diseases of the sternum are rare.

Roentgenography of the sternum is rather difficult. Except some of the bones of the face, it is one of the most difficult bones to show satisfactorily on Roentgen-ray films. This is because of its position directly anterior to the vertebral column and the heart, with the roots of the great vessels, both of which are denser than the sternum. Even when taken in an oblique direction so that its image is projected laterally, its shadow is overlaid by the images of

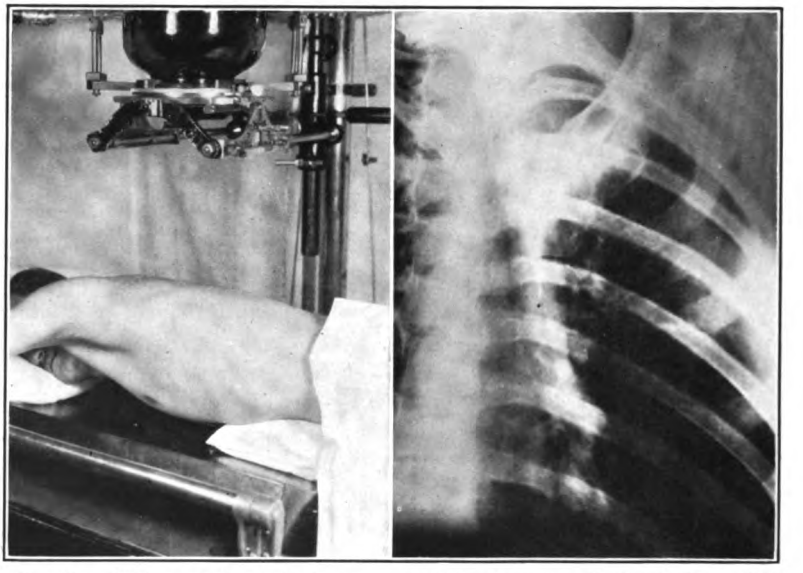

FIG. 91.—Oblique postero-anterior exposure of the sternum with the shadow of the bone displaced to the left of those of the thoracic vertebræ and mediastinum. The left hip and shoulder are elevated on sand bags or pillows.

the ribs, the heart, and the structures in the lung hilus, and is more or less obscured by them.

Because of the greater density of the vertebral column, the heart and great vessels, it is impossible to make roentgenograms of the sternum in the postero-anterior direction; they can be made in either oblique or in a lateral direction. Pfahler believes that the lateral view is the most valuable. The oblique views should be made stereoscopically and preferably with a Potter-Bucky diaphragm; the lateral view may be made either with or without the diaphragm.

For the oblique view, after centering the tube over the diaphragm, the patient is placed in the prone position with the sternum near the center of the diaphragm, then the left shoulder and left hip are raised on sand bags so that the patient is resting on the right side of the anterior chest wall (Fig. 91). This position will project the image of the sternum to the left of those of the vertebral column and mediastinum. The rotation of the patient to the right should be about a fourth of a right angle, or 22½ degrees. A similar view may be made with the body rotated in the opposite direction and so that the left side of the anterior chest wall is against the diaphragm.

The lateral view may be made with a Potter-Bucky diaphragm, using an anode-film distance of 35 inches. The erect position, as recommended by Pfahler, is probably better. The patient either sits or stands with the side of the body against a plate-holding device and the rays are directed horizontally through the bone. A small cone and a rather long anode-film distance (Pfahler uses 40 inches) are necessary. Exposures should be made with respiration stopped during full inspiration.

A 10- by 12-inch film is large enough for any view of the sternum. For the oblique views the central rays should enter the back of the thorax at the level of the spinous process of the fifth thoracic vertebra, a point that can be determined by counting the processes from the vertebra prominens (seventh cervical) downward. For the lateral view, the patient should be so placed that the central ray passes directly transversely through the sternum at a point just below the junction of the manubrium and body.

THE PELVIS.

The pelvis is made up of the sacrum and coccyx behind and the two hip bones laterally and anteriorly. The sacrum is triangular with its base upward. The hip bones are irregular in shape. Projecting from the sides of the sacrum lateralward and toward the front are the broad, curved alæ of the ilii. Inferiorly these form the upper part of the acetabular cavities. The infero-posterior part of each acetabulum is formed by the strong ischium which extends downward to the tuberosity, then turns forward as the more slender inferior ramus. From the acetabulum the superior ramus of the pubis reaches forward and unites with the inferior ramus to form the body of the pubis, the two bodies articulating at the symphysis

pubis in the midline anteriorly. The inferior rami of the pubes extend downward and backward to join with those of the ischii to bound the obturator foramina below.

Fractures of the pelvis, while not common, are not rare injuries, and the increase in automobile accidents is making them more numerous. The pelvis may be fractured in any part by direct violence, or it may be fractured by either lateral or antero-posterior compression. Fractures by direct violence depend entirely on the location, kind, and force of the violence. Those from compression are rather constant in their occurrence. If the compression is antero-posterior, the rami of the pubes and ischium either on one or both sides are fractured, sometimes accompanied by a separation of the symphysis pubis. If the force is continued, an injury of the posterior part of the pelvis results from spreading the hip bones apart. This may be either a vertical fracture through the sacrum or through the posterior part of the ilium, or it may be a separation of the sacroiliac joint from a rupture of the anterior ligaments.

Lateral compression of the pelvis causes much the same form of injury. In front, either the rami of the pubis and ischium give way on one or both sides, or the symphysis is separated. Behind, by forcing the hip bones together, either the sacrum or ilium is fractured or the sacroiliac joints give way from a rupture of the posterior ligaments.

Unless associated with a fracture of the pelvis, sacral injuries are rather rare. They are due to direct violence applied to the bone. Dislocations and fractures of the coccyx resulting from falls or other violence are more common than injuries of the sacrum. Pain, often attributed to the sacroiliac joints, calls for frequent examinations of this region, which usually includes the lumbosacral joints. While these joints are subject to the same diseases as other joints, it is improbable that dislocations or subluxations without fractures are very common.

Roentgenograms of the pelvis are required for the determination of injuries and diseases of the bones or joints. Except for lateral views of the lumbosacral region to detect an anterior displacement of the fifth lumbar vertebra, all of them are made in either the antero-posterior or the postero-anterior direction. Films made for the purpose of examining the pelvis for injury or for the purpose of examining the joints in the posterior part of the pelvis are made in the antero-posterior direction; those for a special examination of the symphysis pubis or the bones of the anterior part of the pelvis are

made in the postero-anterior direction. Whenever available, a Potter-Bucky diaphragm should be used. Since views in the lateral direction are impracticable, stereoscopic films should always be taken.

Unless the violence suspected of causing a fracture of the pelvis is known to be definitely localized, the entire pelvis should be examined. For an adult this requires 14- by 17-inch films with the long axes of the films across the pelvis. The tube should be centered over a point halfway between the umbilicus and the top of the symphysis pubis (Fig. 92). In making stereoscopic films the tube shift should be in the sagittal plane of the body.

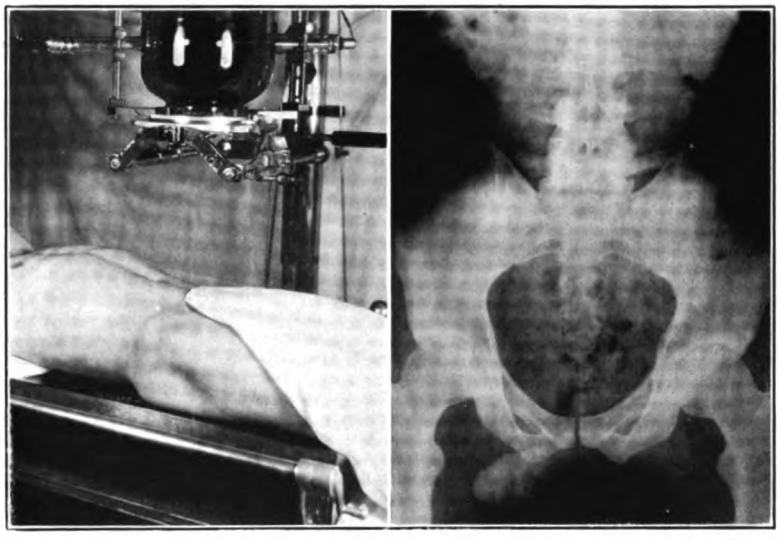

FIG. 92.—Antero-posterior exposure of the pelvis. The tube is centered halfway between the umbilicus and the symphysis pubis.

For views of the sacroiliac joints 10- by 12-inch films are adequate. The tube should be centered as for the entire pelvis and then tilted upward at an angle of 10 degrees. If kept in the line of the grid strips, the tube may be tilted and also shifted for stereoscopic films with the Potter-Bucky diaphragm. By careful posing, 8- by 10-inch films may be used for the examination of the coccyx. The tube should be focused on a point about 2 inches above the upper border of the pubes and then tilted downward at an angle of 10 degrees. Preparation of the patient to empty the colon of its

contents is required. For films of the lumbosacral region, 10- by 12-inch films should be used. This joint is located just above a line connecting the anterior superior iliac spines. For exposures to show this joint, the tube is focused 2 inches below this line and then tilted upward at an angle of 10 degrees.

The only lateral view of the pelvis that is made is for the purpose of determining the condition of the lumbosacral joint and the position of the fifth lumbar vertebra. Bowman believes that spondylolisthesis (a displacement of the fifth lumbar vertebra on the sacrum) is a common injury and emphasizes the importance of making lateral roentgenograms of all patients giving a history of injury or trouble in this region. For this, the patient is placed in the lateral position on the Potter-Bucky diaphragm and the tube focused over a point 1 to 3 inches below the highest point of the iliac crest. The exposure is long (see page 149), requiring immobilization of the patient with the compression band of the diaphragm. It is often advisable to divide the exposure, resetting the grid mechanism before each division. The lumbosacral region and the sacrum may be shown on a 11- by 14-inch film with the long axis parallel to that of the trunk.

For films in the prone position, especially to show the symphysis pubis and adjacent structures, the tube is focused over the coccyx and the rays directed perpendicularly. Although the most frequent and extensive injuries of the pelvis are in the anterior part, because of danger of perforating the bladder or tearing the urethra, patients should never be turned to the prone position for postero-anterior views of injuries.

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CHAPTER XV.

THE HEAD.

ROENTGENOGRAPHY has an important place in the examination of the head and its various parts for the presence of disease or injury. Examinations that are made are those of the vault and base of the cranium for the detection of fractures, examinations of the bones of the face for fractures, examinations of the sella turcica for abnormalities in size and density of the hypophysis; films of the jaws, especially of the mandible, for fractures; extraoral films of the teeth, and examinations of the mastoid air cells and nasal accessory or paranasal sinuses for the presence of infection. Occasionally also roentgenograms are made in a search for evidences of brain tumors and other conditions causing either mental or nervous disorders.

THE CRANIUM.

By cranium is understood that part of the skull which forms the cavity for the brain, commonly called the cranial cavity. Hence, the cranial bones will include all those of the skull which enter into the formation of the cranial cavity. From a practical standpoint, these may be divided into those which assist in forming the vault of the cranium and those which form the base. From the roentgenographic standpoint, there are four subdivisions of the cranial vault. These include the lateral or temporo-parietal regions on each side, the frontal region anteriorly, and the occipital region posteriorly.

Roentgenograms of the lateral or temporo-parietal region of the skull show the posterior part of the squamous portion of the frontal bone, the greater wing of the sphenoid, the parietal bone, the squamous and part of the mastoid portions of the temporal bone, and the anterior aspect of the squamous portion of the occipital bone. The frontal region of the skull is made up entirely of the squamous portion of the frontal bone limited inferiorly by the orbital plates of the same bone. The occipital region is composed of that part of the occipital bone lying lateral to and behind the foramen magnum. On roentgenograms of this region the foramen magnum is shown near the bottom of the film, the mastoid processes project near the

lateral margins, and the lambdoid suture extends across the film like the limbs of an inverted letter V.

The base of the skull is divided into the anterior, middle, and posterior cranial fossæ. The floor of the anterior fossa is formed by the orbital plates of the frontal bones, the cribriform plate of the ethmoid bone, and the upper surfaces of the lesser wings of the sphenoid. The sharp posterior margin of the lesser wings of the sphenoid bone separates the anterior from the middle cranial fossa. The middle fossa is formed by the greater wings of the sphenoid and the temporal bone. The superior angle of the petrous portion of the temporal separates the middle from the posterior fossa. In the posterior fossa are found the temporal bone behind the superior angle, the base and lateral part, and to a small extent, the squamous part of the occipital bone.

Considered as a whole, the cranium provides a rather dense, rigid, bony case for the brain, the cavity within being an irregular ovoid in shape.

Fractures of the cranium are usually divided into those of the vault and those of the base. Fractures of the vault are described as linear, stellate, etc. They are usually produced by direct violence; either the head is struck by a dense object or the head strikes an unyielding object or surface, such as the ground or pavement. Fractures of the base of the cranium are, in a very large proportion of instances, extensions of fractures of the vault. Some few may be due to falls or blows on the chin, knees, feet, or buttocks, resulting in fractures in the temporal or occipital regions from violence transmitted through the mandible or vertebral column. Fractures of the vault extending to the base usually reach the base by the shortest route. Those of the frontal region extend to the base in the anterior fossa; those of the parietal region extend to the base in the middle fossa, and those in the occipital bone reach the base in the posterior fossa.

Symptoms resulting from violence applied to the head, such as unconsciousness, delirium, etc., are due not to the injury of the skull, but to the trauma to the brain. The skull may be extensively fractured through the vault yet there be few symptoms. On the other hand the brain may be seriously damaged and there be no discoverable fracture of any part of the skull. Except where there is an extra-dural hemorrhage or a depressed fracture of the skull, the brain injury is of major and the skull injury of minor importance, and the patient should be treated accordingly.

Roentgenography of the skull of patients who have received a severe cranial trauma is often very difficult. If the patient is delirious or unconscious, or for any reason is not coöperative, considerable perseverance and patience are required, even to the making of more than one exposure of a given region if earlier attempts prove unsatisfactory, or postponing the examination for a day or two until the condition of the patient improves. Chief among the difficulties encountered are immobilization of the part during the exposures and turning the patient to the positions required by the examination.

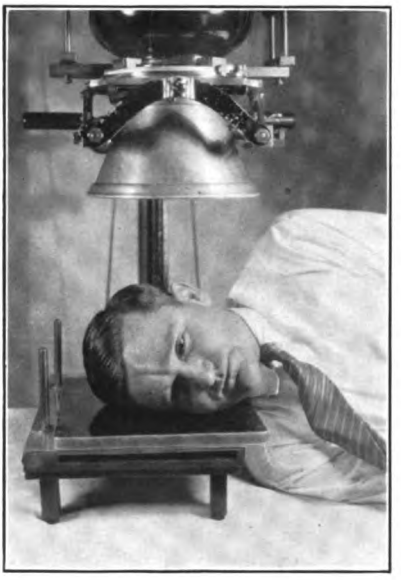

FIG. 93.—Position for a lateral exposure of the skull with the patient in the lateral position and the head elevated on a platform. The sagittal plane of the skull is parallel with the cassette and film.

In these maneuvers, especially the attempts to immobilize the head, the patient should not be roughly handled, for there is danger of increasing the trauma to the brain. Immobilization of the head with a double sand bag is permissible, but the application of tightly fitting head clamps probably should be avoided.

Although contusions, gaping wounds, bleeding from the nose or ears, etc., sometimes may direct attention to the location of a trauma to the skull, roentgenograms always should include more than the region of the injury. Lateral views in both directions, a view of the

occipital region, and, whenever possible, a view of the frontal region should be taken. Stereoscopic films, especially of the part of the skull receiving the trauma, materially aid in tracing fractures of the vault into the base, and are, therefore, preferable to plane films. Better contrast and detail will be present on films made with a Potter-Bucky diaphragm, but often the condition of the patient precludes its use.

For the lateral view the patient may be placed in the lateral position, the side of the head resting on a cassette elevated from the table on a pile of books, an adjustable platform, or a pile of boards as suggested by Stewart (Fig. 93). The position of the head on the cassette should be such that the sagittal plane (an antero-posterior vertical plane dividing the head into two equal lateral parts) is parallel with the surface of the cassette and a line from the upper teeth through the skull to the external occipital protuberance is parallel with the inferior margin of the cassette. In this position a line connecting the pupils of the eyes will be perpendicular to the film. By using an adjustable platform or a pile of boards the head may be raised or lowered until the correct position is obtained. The tube should be centered just in front of the pinna of the ear and level with its upper attachment; a cone or diaphragm just large enough to include the necessary film area should be used; the head should be immobilized with a double sand bag and respiration should be suspended during the exposures.

If the patient is unconscious and a lateral body position difficult to maintain, the prone position, with the head turned sideways, may be used. The opposite shoulder may be elevated with a sand bag and the chin supported on a bandage roll, a large cork, a folded towel, or other non-radiopaque material, holding the head in the desired position (Fig. 94). This position is the most satisfactory for exposures with a portable apparatus and the patient in bed. Occasionally the condition of the patient is such that even turning to the prone position is inadvisable. The only examination then permissible is one made with the cassette on its end at the side of the patient's head with the rays directed horizontally. Films exposed in this manner are frequently unsatisfactory, but they are the best that can be secured. Negative findings from examinations of unsatisfactory films are, of course, of little or no value.

The occipital bone is just as likely to be injured as any other part of the skull. Fractures in this region may not show on lateral views, so that a special film of the occipital region should be a part of every

examination for the detection of skull injury. A direct antero-posterior exposure of the skull will superimpose the images of the orbits, nasal cavities, temporal bones, and other structures on those of the occipital bone. A view of the occipital region must, therefore, be made obliquely from above downward and backward. The tilt of the tube toward the feet may be from 30 to 40 degrees. The patient may be placed in the supine position without elevating the head, the cassette and head be placed on an angle block, or one end

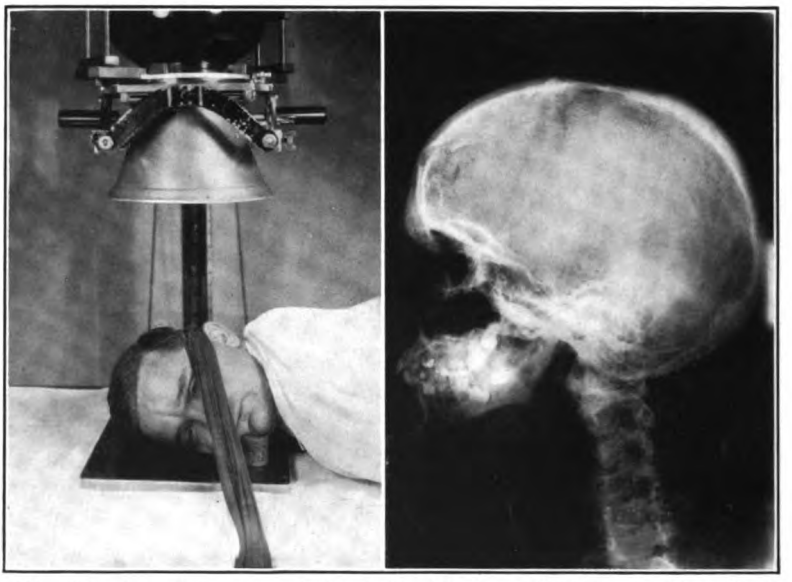

FIG. 94.—Lateral exposure of the skull with the patient prone. The chin is elevated on a large cork to maintain the sagittal plane of the head parallel with the cassette. This position is preferable for comatose patients and refractory children. Except that a smaller cone and a smaller film may be used, this position and the one in Fig. 93 are suitable for exposures of the sella turcica.

of the cassette supported on a sand bag. The angulation of the rays toward the feet may be secured entirely by tilting the tube or by tilting the tube and elevating one end of the cassette (Fig. 95). Stewart recommends the use of a 25-degree angle block and a 15-degree tilt of the tube, making a total angle of 40 degrees. With any method of securing the oblique direction of the rays the cassette is placed under the head with the external occipital protuberance above its center, the central ray is directed into the skull in the sagittal plane and just between and behind the frontal eminences,

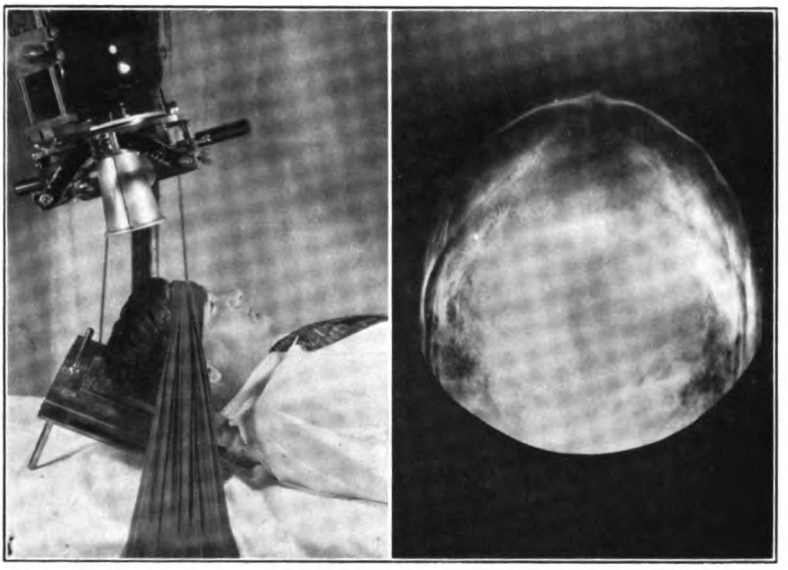

FIG. 95.—Oblique antero-posterior exposure of the occipital region. The combined angles formed by the elevation of the top of the cassette and the tilt of the tube make an angle of 40 degrees. The tube is centered just above and between the frontal eminences.

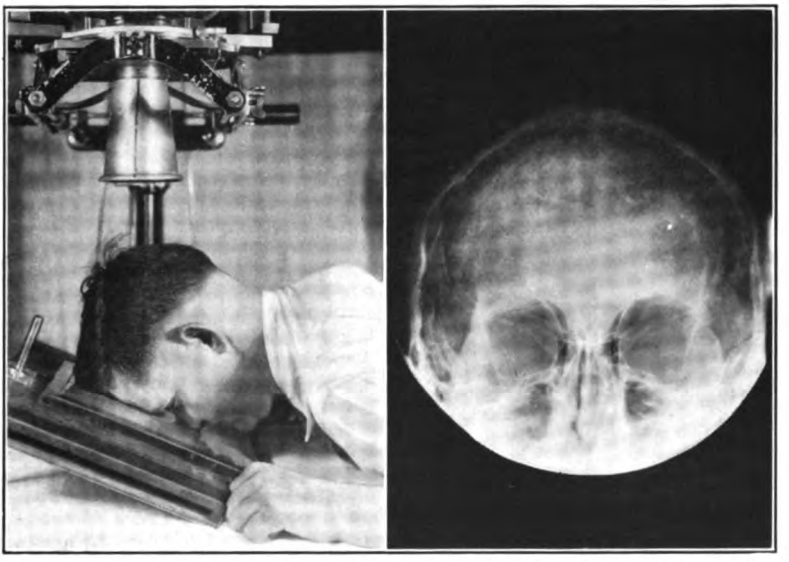

FIG. 96.—Oblique postero-anterior view of the frontal region. The angulation of the cassette and film is 25 degrees, the tube is centered between the parietal eminences.

a small cone or diaphragm should be used, the head should be immobilized, and respiration suspended during the exposures.

A prone position of the patient is necessary for satisfactory examination of the frontal region. The cassette should be elevated on an inclined plane or angle block with an inclination of 20 to 25 degrees. The forehead and nose are pressed against the cassette so that the glabellæ are near its center. The central rays are directed so that they enter between the parietal eminences and emerge at the root of the nose (Fig. 96). The other details of such exposures are the same as those for other films of the skull.

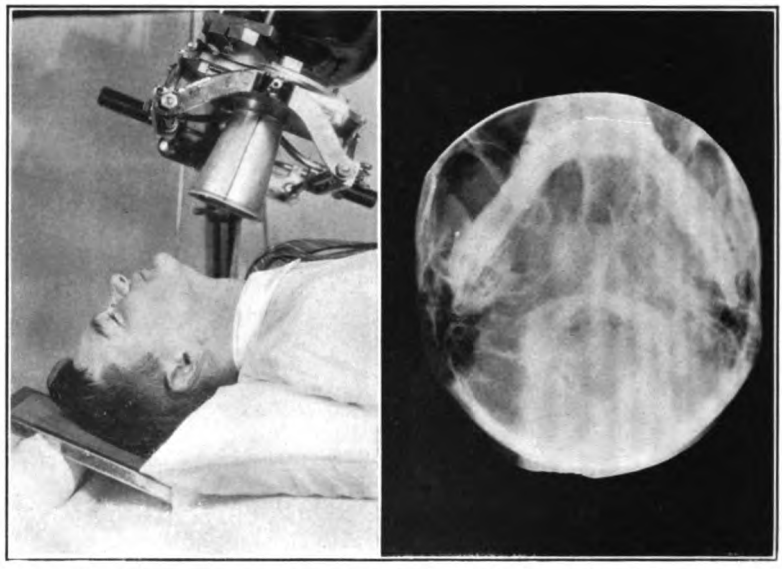

FIG. 97.—Infero-superior exposure of the base of the skull. A line from the external auditory meatus to the lateral canthus of the eye is parallel with the cassette and film; the tube is centered over a point halfway between the larynx and the symphysis of the mandible, the rays being directed perpendicularly to the cassette. This view is the same as that described by Bowen for a film of the sphenoidal sinuses.

The posture required for a view of the frontal region of the skull is such that often it cannot be maintained when dealing with comatose or delirious patients and there may be danger of additional brain injury in attempting to hold the head in that position long enough to make an exposure. It is then advisable to attempt an exposure with the tube under the table and the cassette held against the forehead, or the patient may be turned to the lateral position, the cassette held on its side against the patient's forehead, and the

rays directed horizontally through the head from behind. Should such measures be impossible or fail, it may be necessary to omit this view.

A view of the skull that is useful in determining the extent of injuries is one that is taken in the infero-superior direction as described by Bowen for the examination of the sphenoidal sinuses. This view shows the outline of the mandible and the structures in the base of the skull. It is useful in detecting displacements in fractures of the mandible and zygomatic arches, for determining the size and condition of the sphenoidal sinuses, and for examining the base of the skull. For it, either the shoulders are elevated on pillows or sand bags with the neck extended or the patient is placed on a table so that the head hangs backward over the end, with the vertex against the seat of an adjustable table or stool.

A line from the external auditory meatus to the lateral canthus of the eye should be parallel with the film (Stewart). The tube is centered over a point halfway between the mid-larynx and the symphysis of the mandible (Fig. 97).

For lateral views of the cranium of adults, either plane or stereoscopic, films of the 10- by 12-inch size are required. Views of the frontal, occipital, or basal regions of adults or lateral views of children may be taken on 8- by 10-inch films.

THE BONES OF THE FACE.

Excluding the mandible, which will be considered separately, the only large bones of the face are the maxillæ or upper jaw bones. From a practical standpoint, because of their exposed position, the most important of the bones of the face are the nasal and zygomatic bones. The nasal bones are of small size and oblong shape, situated at the bridge and root of the nose. The zygomatic bones form the prominences of the cheek. They also form parts of the lateral and inferior margins of the orbits, and articulate posteriorly with the long, slender zygomatic processes of the temporal bones to complete the zygomatic arches.

The nasal bones are probably the most commonly injured of the bones of the face. Fractures of the maxilla from violence to the malar bone driving it into the upper jaw, and fractures of the zygomatic arch, usually the more slender temporal portion, are probably the next most common injuries. While in reality a part of one of the bones of the cranium, roentgenography of the temporal

part of the zygomatic arch is similar to that of the bones of the face. Fractures of other bones of the anterior part of the head are rather uncommon. Such injuries are always due to direct violence. If more deeply placed bones, such as the lacrimal or palate, are injured, it is always as a part of some more extensive injury. It is questionable if such injuries are ever recognized, even in the most careful Roentgen-ray examinations.

The satisfactory roentgenographic delineation of injuries around the nose, cheeks, upper jaws, or orbits is rather difficult. In direct

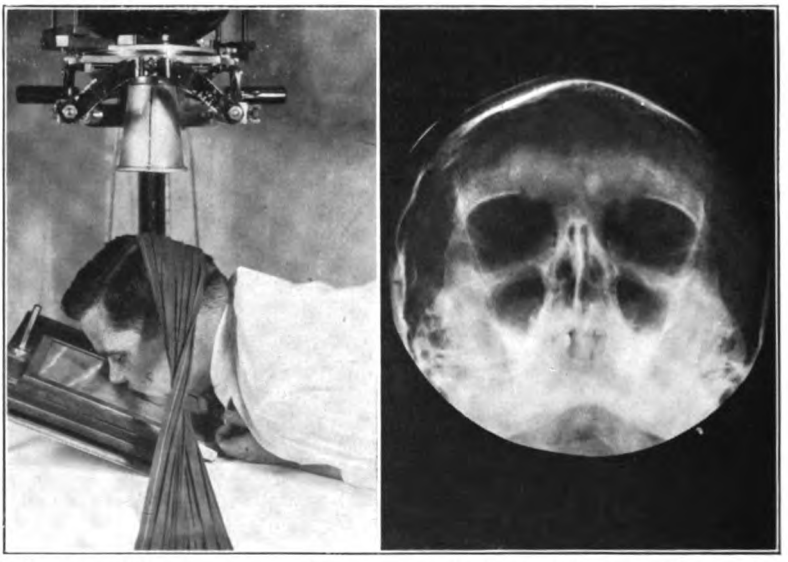

FIG. 98.—Oblique postero-anterior exposure of the bones of the face. The cassette is tilted at an angle of 25 degrees; the chin and nose rest on the cassette; the rays are directed between the parietal eminences.

posterio-anterior and lateral views the images of other structures are superimposed, making identification of different parts either difficult or impossible. Fractures of the nasal bones may sometimes be identified on lateral views of the nose. It is very easy to overexpose such films. The best views of the bones of the anterior part of the head are those made in an oblique direction, with the rays directed from above downward and forward. The images of structures on films made in this manner are very much distorted but they are the best that can be secured.

For this exposure the patient is placed prone on the table with the

chin resting on the cassette below its middle. The amount of elevation of the head is largely a matter of personal choice. Bowen suggests that the cassette should be placed on an angle block with the nose touching the cassette and the rays directed perpendicularly to the table, passing through the top of the head and centering over the incisor teeth (Fig. 98). This is somewhat similar to the Waters position for the nasal accessory sinuses. The position suggested by Titterington is slightly different. The cassette is placed on a 23-degree angle block and the nose and chin pressed against it. The rays are directed perpendicularly, the central rays emerging between the malar bones. For the zygomatic arches the position is the same, but the tube is tilted 15 degrees toward the feet and moved so that the rays pass through the zygoma. The infero-superior view of the base of the cranium as described will also show the zygomatic arches.

For exposures of films of the bones of the face, immobilization with a double sand bag or head clamps and suspension of respiration are essential. A cone or diaphragm just large enough to cover the area being examined will give better contrast and detail. An 8- by 10-inch film is adequate.

THE SELLA TURCICA.

The sella turcica is the cavity in the upper surface of the body of the sphenoid bone in which is lodged the hypophysis or pituitary body. The size of the sella gives an adequate idea of the size of the hypophysis. Hypophyseal tumors increase the size of the sella, and changes in it and in the anterior and posterior clinoid processes result from long continued increased intracranial pressure due to brain tumors or other causes.

In roentgenography of the sella a true lateral view is necessary. The patient's head must be placed in the lateral position, with the sagittal plane of the head exactly parallel with the cassette (Fig. 93). Pfahler has invented a leveling device useful in obtaining the correct position of the head. The sella is located on a line connecting the external auditory meatus with the lower margin of the orbit. The tube should be centered so that the central rays are directed into a point $\frac{3}{4}$ inch above this line and 1 inch in front of the meatus. For the determination of the exact size of the sella, Jewett recommends an anode-film distance of 5 feet, stating that this will give not more than a 5 per cent increase in size due to distortion.

For these views small films may be used. The use of stereoscopic films is an advantage. Immobilization of the head, suspension of respiration, and the use of a small cone are required.

THE MANDIBLE AND DENTAL ARCHES.

The mandible is the largest bone of the face. It consists of a horizontal, curved portion, the body, shaped somewhat like a horseshoe, and open posteriorly. The ends of the body unite with the rami at the angles, the rami extending more or less vertically and dividing at their upper ends into the coronoid and condyloid processes. The condyloid processes articulate with the mandibular fossæ of the temporal bones forming the temporomandibular joints. The upper border of the body of the mandible is known as the alveolar border because it supports the lower teeth, forming the inferior dental arch. Similar borders of the alveolar processes of the upper jaws or maxillæ support the upper teeth, forming the superior dental arch.

Fractures and diseases, such as infections and cysts, of the mandible, and a search for the presence and position of unerupted teeth and areas of infection around the teeth when, for any reason, intraoral films cannot be taken, are conditions which require roentgenographic examination of the mandible or the dental arches. Fractures of the mandible are always produced by direct violence, usually from blows or falls. Although the bone may be fractured in any part of its extent, the usual site is through the socket of a canine tooth or the mental foramen or just anterior to the angle in the third molar region. Double or multiple fractures occasionally occur. Large cysts, either single or multiple, and extensive infections are rather uncommon. Patients with third molar teeth impacted high in the tuberosity of the maxilla or in the angle of the mandible, or those whose mouths are sore from infection, are sometimes examined by making extraoral films.

Roentgenography of the mandible and dental arches is complicated by their horseshoe shape and by the nearness of the occiput of the skull and the cervical vertebræ. On views in the directly transverse direction the images of the bodies and rami of the mandible and the teeth are superimposed and neither side can be positively identified. On films exposed in the postero-anterior direction the images are more or less obscured by those of the skull and spine. In an article published in 1919 by authority of the

Surgeon-General are described methods of overcoming these difficulties. Small parts of the mandible or dental arches are examined at a time and exposures are made in an oblique direction. Six positions are included that show all of the mandible, each one of which is intended to define a certain small region. Two of these are postero-anterior; the others are oblique.

The postero-anterior views are especially useful in determining lateral displacements in fractures of the mandible. While they include the image of the spine, the entire mandible can be seen

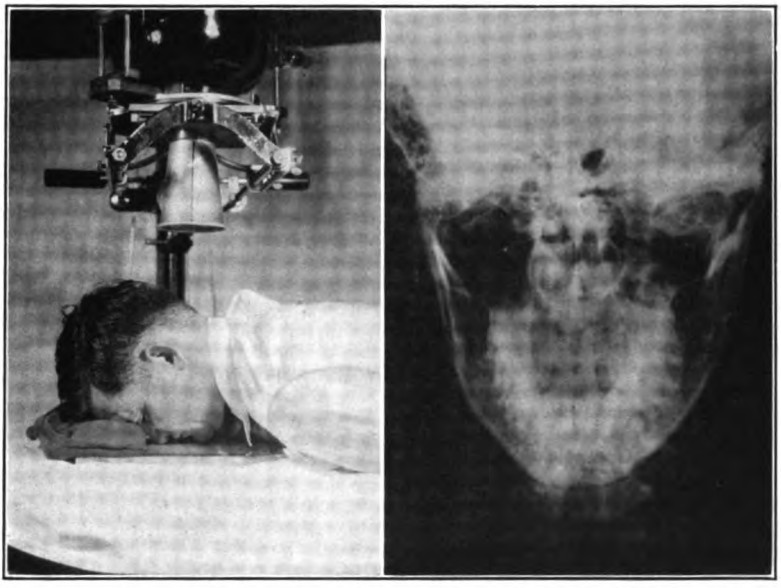

FIG. 99.—Postero-anterior view of the mandible. The forehead rests on a small sand bag; the chin is just off the cassette; a line from the upper border of the external auditory meatus to the lower border of the orbit is perpendicular to the cassette; the tube is centered so that the rays pass halfway between the angles of the mandible.

distinctly enough for the purpose intended. For the first of these views the patient is placed in the prone position with the sagittal plane in the vertical position and the forehead touching the cassette or resting on a small sand bag. The head is adjusted until Reid's base-line (a line from the upper border of the external auditory meatus to the lower border of the orbit) is also perpendicular to the cassette. The chin will be off the cassette. The tube is focused over the back of the neck with the central rays directed perpendicularly to emerge halfway between the angles of the jaw (Fig. 99).

The second postero-anterior view differs from the first in that the nose and chin are pressed against the cassette and the central rays are directed at an angle of 70 degrees toward the vertex, entering through the back of the neck and emerging through the symphysis. In examining a lower jaw that has been fractured, one of these views should always be taken.

Three oblique views are required for a complete examination of the body of the mandible on each side with the corresponding

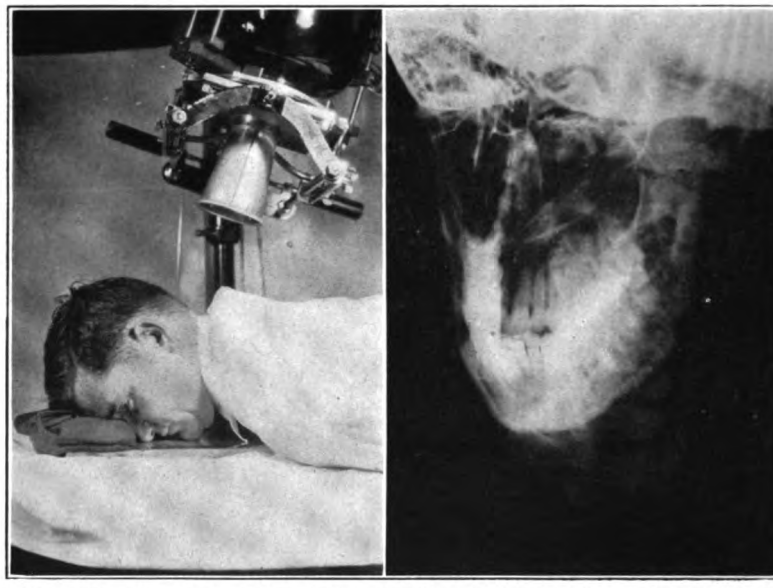

FIG. 100.—First oblique view of the mandible and dental arches to show the region of the symphysis and the canine and incisor teeth. The forehead rests on a small sand bag; the chin just touches the cassette; the head is rotated on a vertical axis so that the body and ramus of the mandible on the side opposite the one being examined (in this case the left) is perpendicular to the film. The tube is tilted toward the top of the head at an angle of 20 degrees, the rays passing between the cervical spine and perpendicular part of the mandible.

upper and lower teeth; the fourth oblique view is used especially to show the ramus. The first oblique view shows the region of the symphysis of the mandible and the incisor and canine teeth; the second shows the body of the mandible in the region of the bicuspid and anterior molar teeth, and the third shows the angle of the mandible and the region of the third molar teeth. On each of these the unobscured area will appear on the film between the image of the vertebral column on one side and the opposite body

and ramus of the mandible on the other. In a given case, the object of the examination and the region to be examined will determine which of the oblique views should be taken.

For the first oblique view the patient is placed in the prone position with the nose in contact with the cassette and the forehead resting on a small sand bag with the chin just touching the cassette. The head is rotated on a vertical axis so that the body and the ramus of the mandible of the side opposite the one being examined

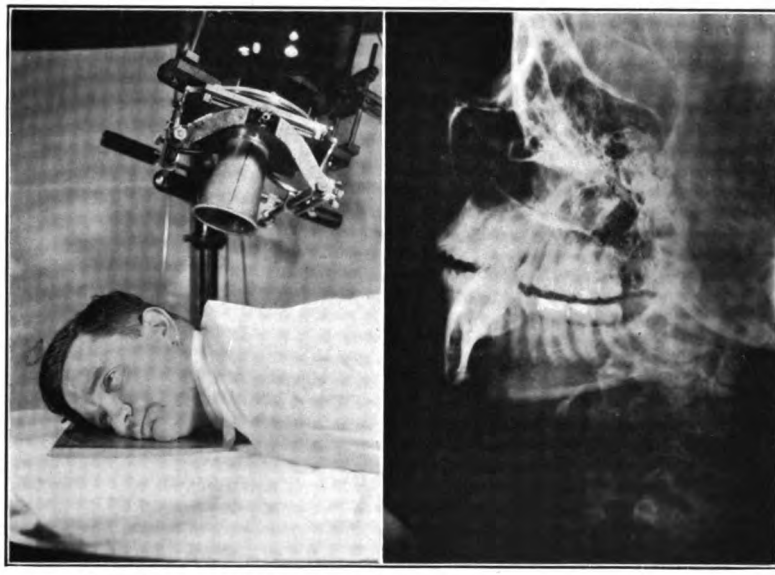

FIG. 101.—Second oblique view of the mandible and dental arches to show the region of the canine, bicuspid, and anterior molar teeth. The side of the mandible is against the cassette; the chin is extended; there is a small sand bag under the occiput; the tube is tilted 10 degrees toward the face and 20 degrees toward the top of the head; the central rays emerge through the middle of the body of the mandible.

are perpendicular to the surface of the cassette (Fig. 100). The tube is tilted toward the vertex of the head, the rays striking the table top at an angle of 70 degrees and focused between the cervical spine and angle of the mandible to emerge through the symphysis.

For the second oblique view the patient's head is placed with the body of the mandible against the cassette and with its inferior border an inch or more from the margin of the film and parallel to it. The side of the chin must be against the cassette, a position that can be maintained if a small sand bag is placed under the occiput.

The head should be extended and the chin elevated as much as possible. The tube is tilted in two directions so that it forms an angle of 80 degrees with the table top toward the chin and an angle of 70 degrees toward the top of the head (Fig. 101). It is focused so that the central rays will emerge at the middle of the body of the mandible.

For the third oblique view the head is placed with the angle of the jaw against the cassette, the side of the chin being slightly elevated. The tube is tilted as for the second oblique view, the rays emerging at the angle of the mandible (Fig. 102).

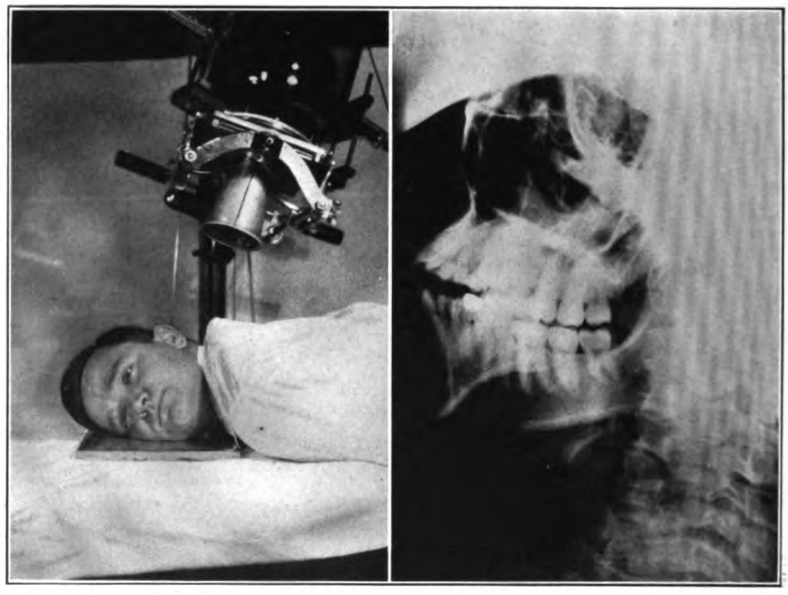

FIG. 102.—Third oblique view of the mandible and dental arches to show the region of the molar teeth. The angle of the mandible is against the cassette; the chin is extended as much as possible; the tube is tilted 10 degrees toward the face and 20 degrees toward the top of the head; the rays emerge through the molar region.

The fourth oblique view is especially useful in showing the ramus of the mandible. For it, the patient is placed in the prone position on the table with the head turned sideways and the sagittal plane parallel with the top of the cassette. The head is extended as far as possible, the chin resting on a bandage roll, a large cork, or other non-radiopaque material. By tilting the tube the rays are directed toward the vertex of the head at an angle of 60 degrees with the

table top (Fig. 103). It is so adjusted that the central rays emerge near the center of the ramus of the jaw on the side being examined.

To secure immobilization for any of these views of the jaws and teeth, a double sand bag should be placed across the head and respiration suspended during the exposures. A cone just large enough to include all of the area being examined will give the greatest detail and contrast. When the tube is tilted and at a

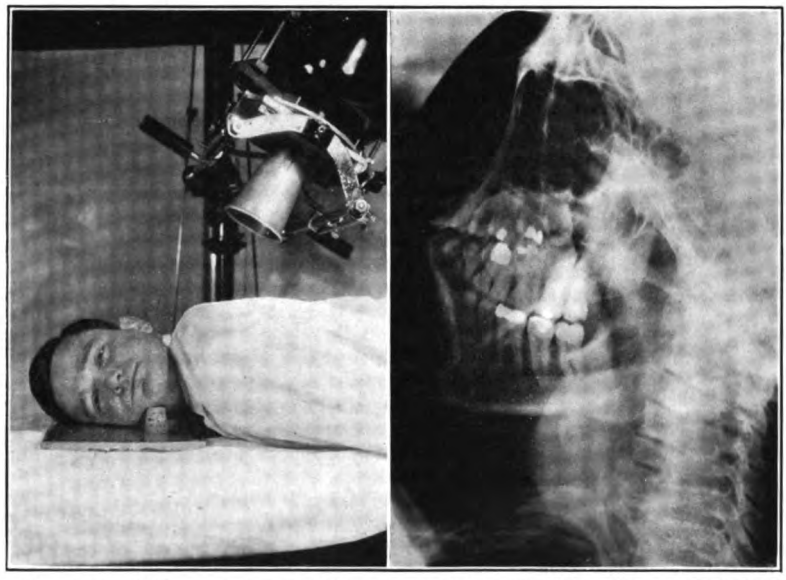

FIG. 103.—Oblique exposure of the ramus of the mandible. The sagittal plane of the head is parallel with the cassette; the chin is extended as much as possible and supported on a large cork; the tube is tilted at an angle of 30 degrees toward the top of the head; the rays emerge through the ramus of the mandible.

distance of 25 inches or more, it is often difficult to accurately focus it so that the rays will be properly directed. This may be done more easily if the filter is removed from beneath the tube and the circle of illumination from the filament used as an aid in centering the tube. The filter should, of course, be replaced before the exposure is made. Small films may be used for these exposures. By careful posing, similar views of both sides of the mandible may be made on one $6\frac{1}{2}$- by $8\frac{1}{2}$-inch film divided transversely.

THE MASTOID REGIONS.

The mastoid processes of the temporal bones are cellular structures usually containing air, the spaces of which are connected with the middle ear by the mastoid antrum. Occasionally some will be encountered of the diplöic type that do not contain air or one will be found that has undergone a complete sclerosis. Usually they are pneumatic, of variable size, and containing cells of different dimensions. The smaller cells are located just around the antrum and extending forward into the root of the zygoma, while the larger ones are along the posterior border and around the tip of the process. Mastoiditis is a common infection during epidemics of measles, scarlet fever, and influenza. Roentgenograms, if properly made and correctly interpreted, are a great help to the otologist in detecting the presence, extent, and degree of infection of the mastoid cells.

Because of the bilateral symmetry of the temporal bones, views of the mastoids in the directly lateral direction cannot be made; to obtain unobscured images, recourse must be had to views taken in an obliquely lateral or other oblique direction. For the obliquely lateral views, the patient must place the side of the head against the cassette, a procedure that is often very painful. To overcome this difficulty and to show portions of the temporal bone that are not clearly shown on the lateral films, various oblique antero-posterior or postero-anterior projections have been devised. Of the obliquely lateral views the best known in this country is that taken in the Law position. This projection is somewhat similar to that of Schueller as described by Mayer. For showing the condition of the mastoid cells Arcelin (given by Granger) has described a postero-anterior oblique projection and Granger an antero-posterior oblique view. Mayer also described an exposure attributed to Stenvers and one devised by himself for showing parts of the temporal bone not so clearly shown on the obliquely lateral views. The best of the obliquely lateral views is that made in the Law position; probably the best of the other projections is that described by Granger.

Views of the mastoids in the Law position can be made without the use of a mastoid localizer. The essentials of the method consist in having the sagittal plane of the head parallel with the cassette and film, tilting the tube toward the face and toward the feet at angles of 15 degrees, and directing the central rays into the head 2 inches above and 2 inches behind the external auditory meatus of the opposite side. In this position the rays pass directly through

both the external and internal auditory meati so that they appear as a single dark spot on the film. Around this will be the compact bone forming the wall of the tympanic cavity, behind which will be the cellular portion of the mastoid with the image of the groove for the lateral (sigmoid) sinus extending vertically across its posterior part (Fig. 105).

For the Law position the patient is placed in the lateral position with the head supported on blocks or a small platform (Fig. 104).

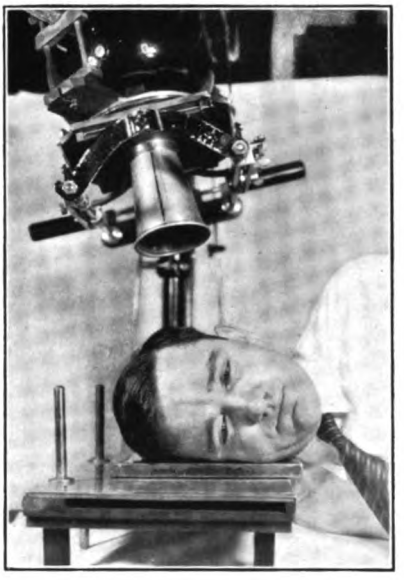

FIG. 104.—Law position for exposures of the mastoid regions. The patient is in the lateral position; the head is elevated on a platform with the sagittal plane parallel with the cassette; the tube is tilted 15 degrees toward the face and 15 degrees toward the feet, the central rays entering 2 inches above and 2 inches behind the external auditory meatus to emerge through the opposite mastoid region. The prone position of the body, as shown in Fig. 94, also may be used and is preferable for children.

One-half of an 8- by 10-inch cassette is covered with a piece of sheet lead, the uncovered half is slipped under the patient's head, and the head adjusted in height so that the sagittal plane is parallel with the surface of the cassette. The head is lifted up, the pinna of the ear turned forward and the head replaced, at the same time adjusting the cassette so that the mastoid process is at the center of the uncovered portion. The tube is tilted and focused with the central rays entering at the proper place

and emerging through the mastoid being examined. The immobilizing device, either head clamps or a double sand bag, is then

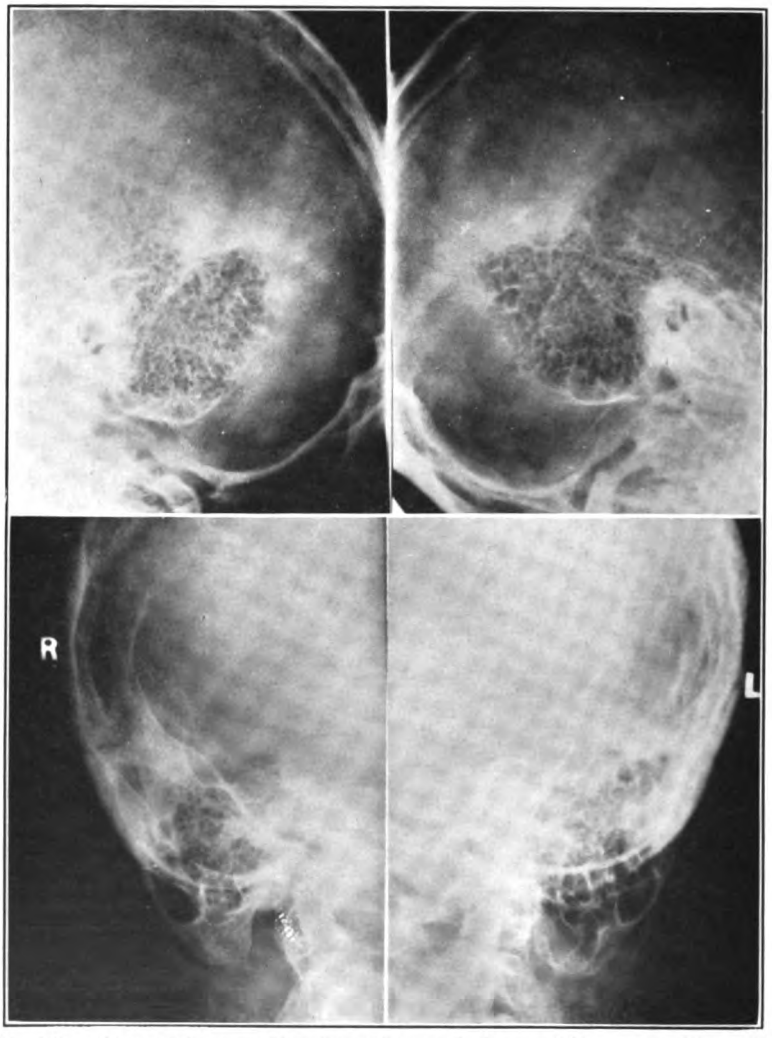

FIG. 105.—Films of the mastoid regions taken in the Law and Granger positions with the aid of a Granger mastoid localizer.

adjusted and the patient is ready for the exposure. Respiration should be suspended. A view of the opposite mastoid is then made on the other half of the same film. Law calls attention to the fact

that, if the head cannot be placed in the proper position, the deviation of the head must be compensated for in the tilting of the tube.

Children often require a Roentgen-ray examination of the mastoid regions. Should they prove refractory, considerable difficulty will be experienced in obtaining satisfactory films. It probably is better to place these patients in the prone position on the table with the head turned lateralward and with the upper extremity of the side being examined at the side of the trunk. They can be better controlled in this position than if an attempt is made to elevate the head. The details of the exposure in this position are the same as those given above.

Various devices in the form of angle blocks and accessory apparatus for making plane and stereoscopic films of the mastoid regions have been described by Aspray and Herpel, Pfahler, Bullitt, Pancoast, Bowen and Bishop, Granger, and others. The apparatus described by Granger for films in the Law position and in his oblique antero-posterior projection has proved very satisfactory. Either plane or stereoscopic films can be made with it (Fig. 106). By its use, exactly similar views can be made of both sides of the same patient, and there is a similarity in those of different patients. It consists of a double angle block, a base which fits over an 8- by 10-inch cassette covering one-half of it with lead, and an upright piece into which the patient's nose is placed so that the upper alveolus and glabella are in contact with it. The angle block compensates for the tilt of the tube, permitting directing the rays perpendicularly to the top of the table. The piece against which the nose rests is adjustable in height, making it possible to place the head with the sagittal plane exactly parallel with the surface of the cassette. The device is constructed so that when it has been adjusted for one side, it may be turned around and the same adjustment used for the other side, thus giving similar views of both mastoid regions.

An attachment is included by the use of which views of the mastoids may be taken in an oblique antero-posterior direction (Fig. 106). For this a single angle block is used, tilted toward the feet at an angle of 15 degrees. The patient is placed in the supine position with the head on the block. The head is turned lateralward, the sagittal plane forming an angle of 50 degrees with the film. The attachment provides a position for the nose with the upper lip and glabella in contact, and makes it possible to make comparable exposures of opposite sides. The tube is focused 2 inches in front of and 1 inch above the external auditory meatus with the rays directed perpendicularly to the table top.

In making roentgenograms of the mastoid region, the greatest care should be exercised to be certain that the identifying numbers and letters R and L, designating the two sides of the film, are correctly placed. Since a large part of the interpretation of the films is based on a comparison of the appearance of the images of the two sides, care should also be taken to use identically the same exposure factors, giving two images of exactly the same roentgenographic density.

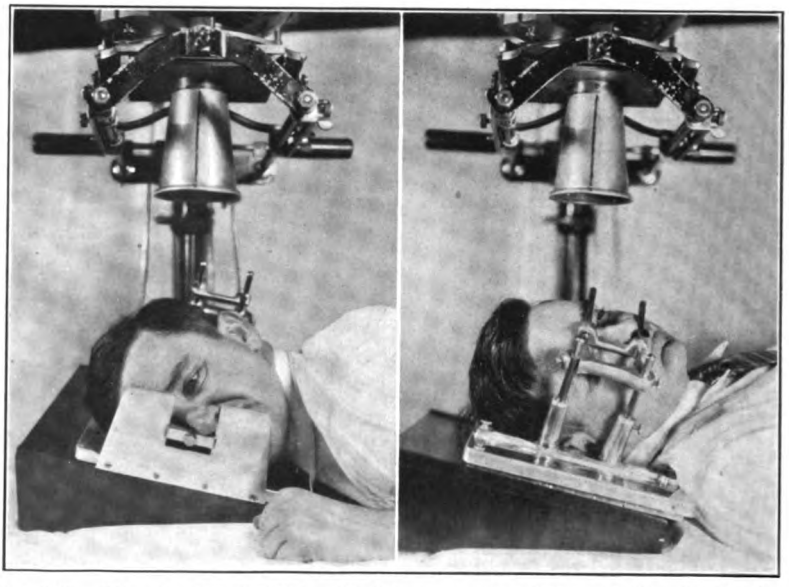

FIG. 106.—The adjustment of the patient for exposures of the mastoid regions in the Law and Granger positions with the use of a Granger mastoid localizer.

By using a cassette-changing tunnel for changing the cassettes, either with or without the use of an angle block or mastoid localizer, stereoscopic films of both mastoids can be made on two 8- by 10-inch films.

THE NASAL ACCESSORY SINUSES.

From the bones in which they are located, the nasal accessory or paranasal sinuses are called the maxillary, frontal, ethmoidal, and sphenoidal sinuses.

The maxillary sinuses, the largest of all, are two in number, located one in each upper jaw just beneath the cheek. They are pyramidal in shape, with each of their three dimensions measuring

more than 1 inch. They are separated by plates of bone from the cheek in front, the nasal cavities medially, the orbits above, the upper teeth and mouth below, and the pterygopalatine fossæ and pterygoid processes posteriorly. While they are of different sizes in different persons, they seldom vary much in size in the same individual. They communicate by one or more openings with the middle meatus of the nose. They are more often infected than any other of the nasal sinuses.

The frontal sinuses are located in the frontal bone just above and between the orbits and above the root of the nose. They are more variable in size and extent than any of the others. Either one or both may be entirely absent or only represented by a small pocket in the bone. Occasionally they are very large, extending entirely across the orbits, high into the squamous part of the frontal bone, and horizontally backward in the orbital plates of the bone. The average dimensions are about 1 inch horizontally and transversely and slightly more vertically. They are rarely of equal size in the same person, the septum between them being deflected to one side. More often the right is the larger. The frontal sinuses are related to the forehead anteriorly, the orbits inferiorly, and the cranial cavity posteriorly. Each communicates by a narrow canal with the middle meatus of the nose.

The sphenoidal sinuses are two in number, located in the body of the sphenoid bone. Their average dimensions are from $\frac{3}{4}$ to $\frac{7}{8}$ inch. They are separated by a septum which may be in the midline or displaced to one side. Because of this, one sinus may be larger than the other. Occasionally one is entirely absent. The sphenoidal sinuses are related to the base of the brain, the internal carotid arteries, the cavernous sinuses, the optic chiasma, and other important structures. Each communicates by a small opening with the upper posterior part of the nasal cavity.

The ethmoidal sinuses are the smallest of the series. They are in two sets, one in each lateral mass or labyrinth of the ethmoid bone. These portions of this bone extend downward from the cribriform plate between the orbits laterally and the nasal cavities medially. The ethmoidal cells are variable in number and in size. They are usually small, with thin walls, and from three to fourteen in number on each side. The cellular portions of the ethmoid bone in the same person are only occasionally of unequal extent. Those cells in the anterior portions of the ethmoidal labyrinth open into the middle meatus of the nose and are spoken of as the anterior cells. Those in

the posterior part open into the superior meatus of the nose and are called the posterior ethmoidal cells. These two groups are not separated by a distinct septum.

The nasal accessory sinuses are often infected, causing nasal discharge, fever, headache, eye disorders, asthma, chronic cough, and other forms of illness. They are placed within the bones of the skull, are of variable size and irregular extent, making their examination difficult. Any method of investigating the condition of these sinuses, therefore, is of distinct value. Probably the best direct method of examination is by roentgenography. Skillfully made and wisely interpreted roentgenograms are of inestimable value in seeking for infection in these spaces.

There are two chief difficulties in making roentgenograms of the nasal accessory sinuses. Because of their position within the skull, especially the posterior ethmoidal and sphenoidal, and the consequent impossibility of placing them close to the film, their images are always more or less distorted. The second difficulty lies in the fact that it is impossible to make films of the skull without projecting on to them images of all parts of the skull through which the rays pass. Thus, if the shadows of the petrous portions of the temporal bone or the floor of the posterior cranial fossæ are placed across those of any of the sinuses, the shadows of the latter are obscured.

To overcome these two difficulties numerous methods of making films of the sinuses have been devised. Lateral and oblique views, postero-anterior views at different angles, infero-superior and supero-inferior projections, and intraoral films have been used. Postero-anterior views, which permit of comparison of the same region on opposite sides of the skull, are probably the best. To secure images of all the sinuses unobscured by the petrous portions of the temporal bones or other structures and with distortion reduced to a minimum, more than one film is necessary. Of the postero-anterior projections that have been described, those of Waters and Waldron, Caldwell, and Granger are the best known.

In the Waters-Waldron position the head is placed so that the shadows of the petrous portions of the temporal bones are projected below those of the maxillary sinuses. It is particularly useful in examining the frontal, ethmoidal, and maxillary sinuses. The rays are directed from above and behind, downward and forward, in an oblique postero-anterior direction. The images will, therefore, appear as oblique postero-anterior projections. The anterior ethmoidal appear above the posterior ethmoidal cells.

For the exposure of films in the Waters-Waldron position the patient is placed on the table in the prone position with the chin resting on a cassette just below its middle. The sagittal plane of the head must be perpendicular to the film and along its long axis. The tip of the nose must be off the cassette. Waters and Waldron say that for those with a convex-shaped face the nose must be 1 centimeter from the cassette, and for those with a concave-shaped face it should be 1.5 centimeters off the cassette. The rays are

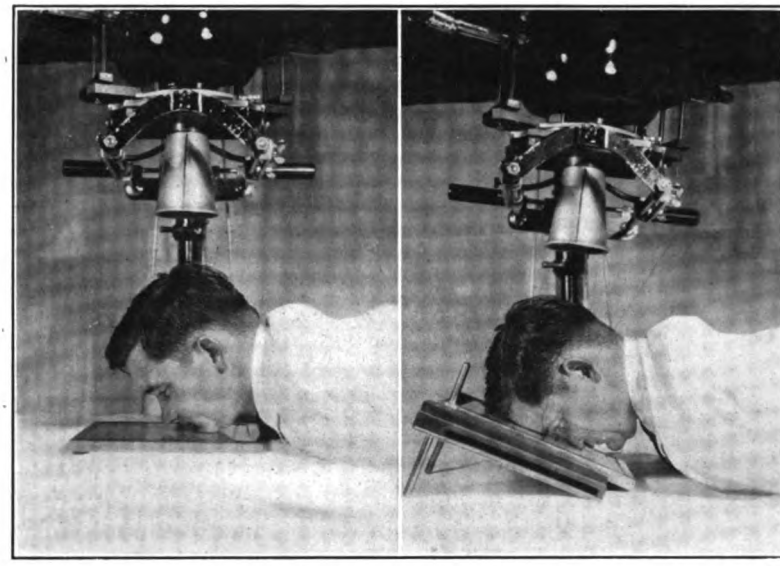

FIG. 107.—At the left, adjustment of the patient for an exposure of a film of the nasal accessory sinuses in the Waters-Waldron position. The chin rests on the cassette; the nose is 1 centimeter off the cassette; the tube is centered so that the central rays emerge through the nose. At the right, the arrangement of the patient for a film of the nasal accessory sinuses in the Caldwell position. The cassette is elevated and the tube tilted so that the central rays form an angle of 23 degrees with a line extending from the external auditory meatus to the glabella and emerge through the root of the nose.

directed perpendicularly to the cassette and so centered that the central rays emerge through the nose (Fig. 107). Immobilization by means of head clamps, or a double sand bag, and suspension of respiration are essential.

The Caldwell position gives almost a true postero-anterior projection of the nasal sinuses. On films made in this position the shadows of the petrous portions of the temporal bones fall two-thirds across the lower parts of the orbits and one-third across the

upper parts of the maxillary sinuses. Such films are particularly good for the frontal sinuses and show the inferior portions of the maxillary sinuses. The shadows of the anterior and posterior ethmoidal and sphenoidal sinuses are more or less superimposed.

For exposing films of the sinuses in the Caldwell position, the cassette is placed on an inclined plane or angle block having an angle of from 15 to 25 degrees, with the patient's forehead and nose pressed against the cassette with the nose just below its middle. The sagittal plane must be perpendicular to the cassette and along its long axis. The tube is tilted so that the central rays pass through the head, forming an angle of 23 degrees with a line extending from the external auditory meatus to the glabella (Fig. 107). To assist in directing the tube, Law has devised an angle of 23 degrees with a long and short arm, the former 16 inches and the latter 6 inches in length. This is held at the side of the patient's head with the short arm extending from the meatus to the glabella and the tube adjusted so that the central rays coincide in direction with the long arm of the angle.

The Granger position is especially designed to give information about the sphenoidal sinuses. The head is placed at an angle of 107 degrees with the vertical, or 17 degrees with the horizontal, and the rays directed in an oblique postero-anterior direction from behind forward and upward. The shadows of the petrous portions of the temporal bones fall within those of the orbits. On views made in this position the rays have passed tangentially through the bone forming the floor of the optic groove in the roof of the sphenoidal sinuses, causing it to appear as a curved line called by Granger the G line (Fig. 115). Information with reference to the sphenoidal sinuses is derived from the appearance of this line and the region immediately below it. Experience has taught those who are familiar with this method to place great confidence in Granger's conclusions concerning the diagnostic significance of films made in this position.

Satisfactory films in the Waters-Waldron and Caldwell positions can be made without the use of a special sinus block or board; but, since the angle must be exact, for films in the Granger position such an accessory apparatus is necessary. The one designed by Granger is very satisfactory. This block utilizes what Granger calls the alveolo-glabellar position. There is a hole in the top of the block in which the patient places his nose, the head resting below the hole on the upper lip, alveolus, and teeth, and above the hole on the glabella. Provision is made for two views, one with the top of the

block forming an angle of 23 degrees with the top of the table and the other in the Granger position. The film exposed with the top in the 23-degree angle position (this angle must not be confused with the 23-degree angle used in the Caldwell position) is somewhat similar to one made in the Waters-Waldron position in that the petrous portion of the temporal bones are below the maxillary antra or across their lower portions.

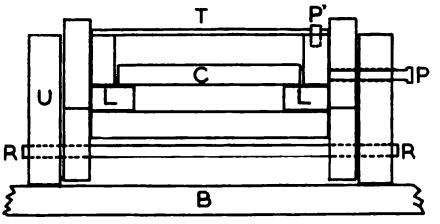

FIG. 108.—Front elevation of the modified Granger sinus block as described in the text.

An angle block of the Granger type, utilizing the alveolo-glabellar position, simplifies roentgenography of the nasal sinuses and provides a method of duplicating results difficult to obtain in any other way. A film exposed in the Caldwell position may be used as a

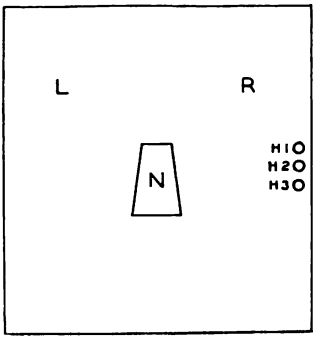

FIG. 109.—The top of the angle block, showing the opening for the nose, the identifying letters R and L, and the three holes for shifting the top for the three exposures.

check on the one made in the 23-degree position. A simple modification of the Granger block makes provision for this position also. In addition to the two positions advocated by Granger, provision is made for fixing the top nearly horizontal, sloping at an angle of only 3 degrees toward the patient's feet. Films exposed with the top at

this angle will be in the Caldwell position. The use of this block has been so satisfactory that its construction will be described.

Figs. 108 to 112 show this modification of the Granger sinus block (see Figs. 113, 114, and 115 also). It consists of a base (B) made of 1-inch lumber, 8 inches in width and as long as the table is wide.

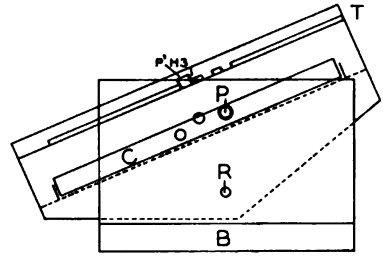

FIG. 110.—The angle block in position for the exposure in Granger's first position, the 23-degree angle position. (See Fig. 113.)

To this are fastened securely two uprights (U) which support the block. The block is fitted snugly between the uprights and is permitted to rock back and forth by the rod (R). The ledges (L) support the cassette (C) so that its upper surface is 1 inch from the top (T). The top is made of celluloid or bakelite. It has in it the hole for the nose (N), the location and dimensions of which are shown in Fig. 109. It is removable so that it can be cleaned. To

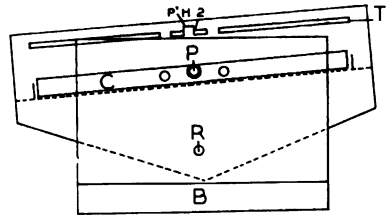

FIG. 111.—The angle block with the top nearly horizontal for exposure of a film in the Caldwell position. (See Fig. 114.)

its lower surface are fastened lead letters R and L to designate the right and left sides of the patient's skull. The different positions are secured by tilting the block. It is held at exactly the right angle by the pin (P) which passes through a hole in the upright into either of three holes in the side of the block.

To keep the hole for the nose over the center of the cassette in the different positions, the top must be moved. On the right side of the top are three holes (H^1, H^2, and H^3), ½ inch apart, which fit over the peg (P′). When the block is tilted at the 23-degree angle, the peg should be in the hole H^3 (Fig. 110); when it is tilted at an angle of 3 degrees, the peg should be in the middle hole (Fig. 111), while in the Granger position the peg should be in hole H^1 (Fig. 112). If it is appreciated that for the first and third positions the top is moved in the direction opposite the tilt of the block, this is easily remembered.

This block is made to accommodate cassettes for 6½- by 8½-inch films, a size which has been found large enough for all views of the sinuses. One could easily be made enough larger to accommodate 8- by 10-inch films.

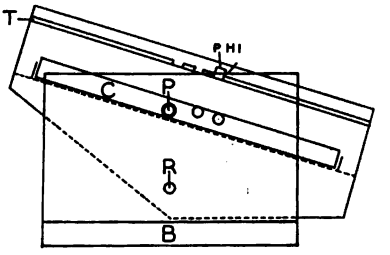

FIG. 112.—The angle block with the top tilted at an angle of 17 degrees beyond the horizontal for exposure of a film in the Granger sphenoid position. (See Fig. 115.)

In exposing films of the cranial sinuses with a block of this sort, it is placed near one end of the Roentgen-ray table, tilted at the desired angle, with the top in the proper position, and the cassette in place. The tube stand is fitted with a cone which should not be larger than 2½ inches at the smaller end and 4 inches at the larger. This should be accurately placed over the hole for the patient's nose, and the tube swung up out of the way until the patient's head is in place. The patient lies prone on the table, supporting the chest on the elbows, with his nose in the hole, his head making equal pressure above and below the hole (Figs. 113 to 115). The sagittal plane of the patient's head should be perpendicular to the top of the table and exactly in the long axis of the top of the block. To assist in immobilization, a double sand bag is placed across the head. The anode-film distance is then measured, the tube moved to the proper height, the patient is instructed to hold his breath, and the exposure is made. When one film has been exposed, it is

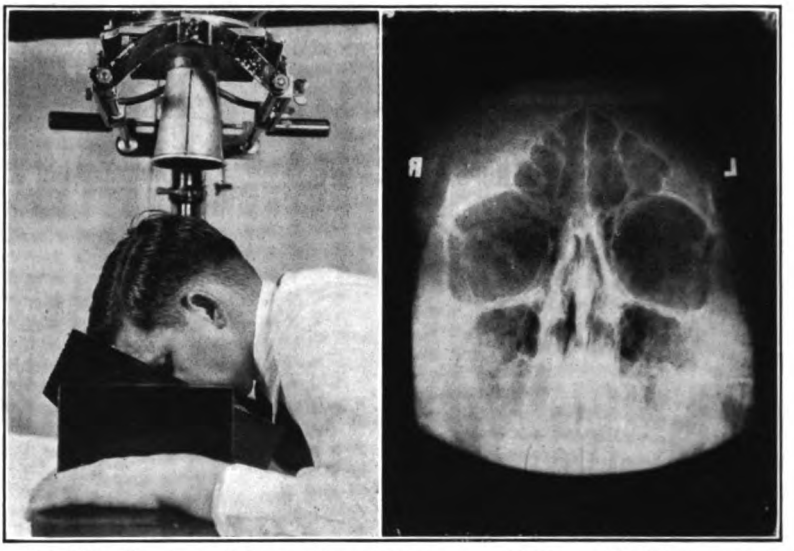

FIG. 113.—Exposure of the nasal accessory sinuses with the modified Granger angle block described in the text. The alveolo-glabellar position is utilized; the top of the block forms an angle of 23 degrees with the table. The film is somewhat similar to that obtained in the Waters-Waldron position.

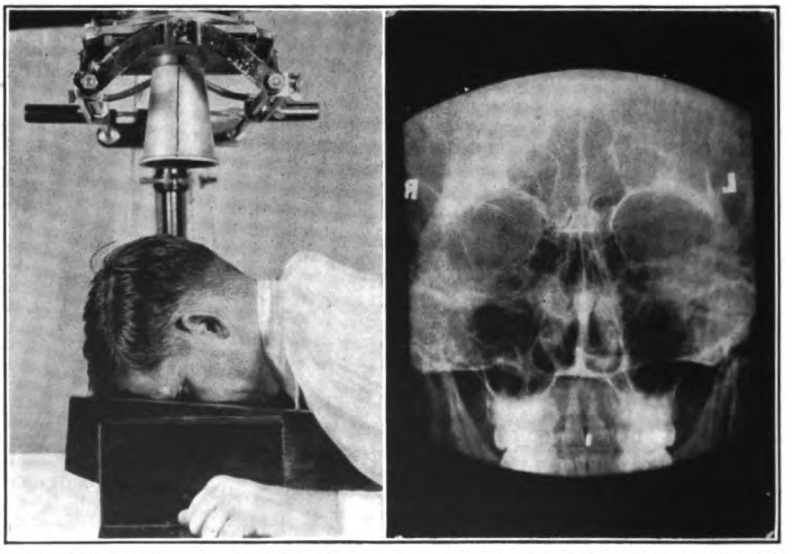

FIG. 114.—Exposure of the nasal accessory sinuses in the Caldwell position with the modified Granger angle block described in the text. The alveolo-glabellar position is utilized, the top of the block forming an angle of 3 degrees with the top of the table.

necessary to have the patient sit up while the block is being adjusted and the tube centered for the exposure in the next position.

Films through the regions of the sinuses in the lateral position are valuable for determining the topography of the sinuses, but considerably less important than postero-anterior views for determining the presence of infection. In lateral views the sinuses of opposite sides are superimposed thus obscuring the images of those on both sides. While often omitted as a routine, they are sometimes made to determine the depth and height of the frontal sinuses,

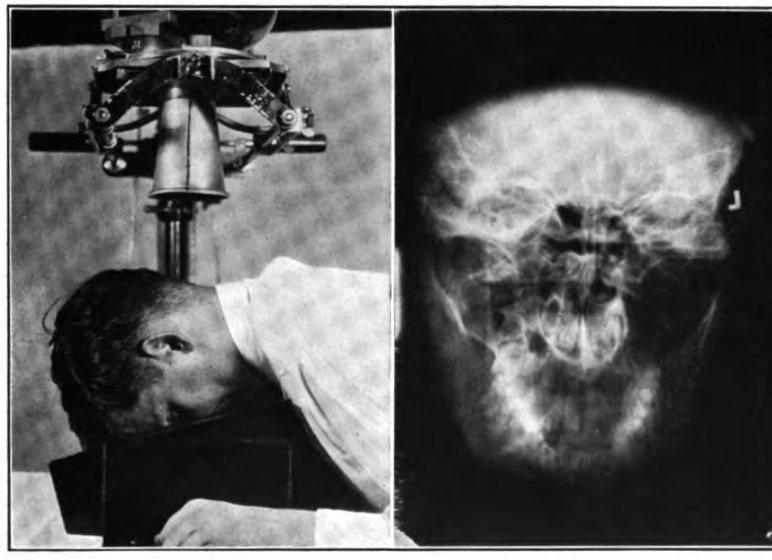

FIG. 115.—Exposure of the nasal accessory sinuses in the Granger position. The alveolo-glabellar position is used, the top of the angle block forming an angle of 17 degrees beyond the horizontal with the top of the table. The central rays from the tube pass just inferior to the external auditory meatus.

the thickness of their anterior walls, and for determining the size of the sphenoids and their distance from the anterior nares. For the lateral view the head is placed on a small platform or pile of boards with the sagittal plane parallel with the cassette under it. For the frontal sinuses the rays are directed through the frontal region; for the sphenoid sinuses they are directed as given under the examination of the sella turcica. Immobilization, suspension of respiration, etc., are essential.

A black border around films of the sinuses improves their appearance and, by increasing contrast, assists in the interpretation. To

make this border, the central part of the cassette is covered with a piece of sheet lead of suitable size and shape, an identifying number is placed at the top of the cassette, and the border of the film is exposed to a small quantity of rays.

WITH A POTTER-BUCKY DIAPHRAGM.

Because of the absorption of scattered rays when large areas are examined, a Potter-Bucky diaphragm can be used to advantage for many exposures of parts of the head. It is especially useful in those instances when films of the entire skull are exposed, when tilting of the tube to obtain the desired view does not prohibit its use. Films of the cranium in all of the four directions, of the sella turcica and bones of the face, and views of the nasal sinuses in the Waters-Waldron and Caldwell or similar positions can be made with a diaphragm. For small portions of the head, as the sella turcica, the mastoid regions, the different exposures of the mandible, and even the nasal sinuses, which permit of the use of a small cone, films without are about as satisfactory as those exposed with one, hence a diaphragm is not generally used for such exposures. Accessory apparatus, such as a mastoid localizer or sinus block, cannot, of course, be used with a Potter-Bucky diaphragm.

Whenever available and whenever the condition of the patient permits, a diaphragm should be used for films of the cranium and face to detect bone injury and for a study of cranial contents. As in all other parts of the body having a complicated structure, stereoscopic are preferable to plane films. The patient's head must be placed against the top of the diaphragm in the required position without the use of a platform or other apparatus that might be used without the diaphragm. With this exception the posing of the patient is the same as that already given. The compression band of the diaphragm serves as an excellent immobilizing device.

Since the separation of the part and film by the grid and top of the diaphragm, especially when examining a large part like the head, considerably increases distortion, a 30- or 35-inch anode-film distance is preferable to the usual 25-inch distance.

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CHAPTER XVI.

THE TEETH.

In roentgenography of the teeth, the first important essential is a knowledge of the appearance and the arrangement of the teeth in the alveolar processes of the jaws. Only the major facts can be given here. For the details standard texts on medical or dental anatomy should be consulted.

There are eight teeth in each half of each jaw (Fig. 116). From the center in front, backward, these are named the central and lateral incisor teeth (I, Fig. 116), the canine or cuspid tooth (C), the first and second premolar or bicuspid teeth (P), and the first, second, and third molar teeth (M). Each tooth has a crown which

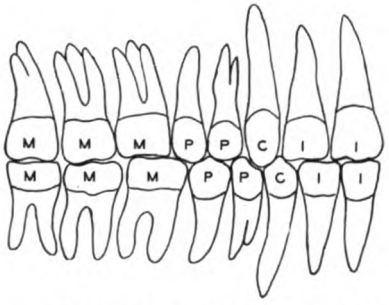

Fig. 116.—The teeth in the right half of the upper dental arch. I, incisor teeth; C, canine tooth; P, premolar or bicuspid teeth; M, molar teeth.

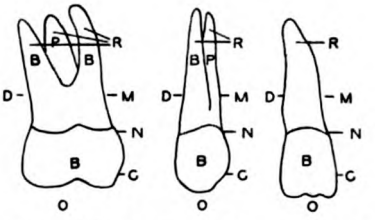

Fig. 117.—An upper incisor, premolar, and molar tooth showing the different parts. The explanation is given in the text.

projects above the gum (C, Fig. 117), a neck which is surrounded by the gum margin (N), and one or more roots extending into the bone of the jaw (R). The incisor teeth have a chisel-shaped crown with a single conical root. Those in the upper are larger than those in the lower jaw. The crowns of the canine teeth are large and conical. The roots are single and cone-shaped and are the longest of any of the teeth. In cross-section the crowns of the premolar and molar teeth are more or less quadrilateral. The premolars have a flat root which may be divided at the tip. The upper molar teeth

each have three roots (Fig. 117), one diverging mesially and known as the palatal or lingual root (P), and two on the lateral aspect, nearly parallel with each other, and known as the buccal (bucca, cheek) roots (B). Each lower molar has two roots, an anterior and a posterior, or mesial and distal.

Each tooth has an occlusal aspect (O, Fig. 117)—that which looks toward the opposing tooth in the opposite jaw. While this is of small extent on the canines and incisors, the premolars and molars present a distinct, although irregular, occlusal surface. That part of the tooth which is toward the midline of the teeth (in dental anatomy the space between the central incisors) is called the mesial surface (M, Fig. 117), and that away from the midline is called the distal surface (D). The surface toward or in contact with the check is known as the buccal surface (B), and that toward the tongue or palate is the lingual (lingua, tongue) or palatal surface. The space between two adjoining teeth is known as the proximal space, the surfaces being known as the proximal surfaces.

The alveolar processes of the upper jaw and the alveolar margin of the lower jaw, with the contained teeth, are shaped much like a horseshoe and are sometimes called the alveolar or dental arches (A, Figs. 122 and 124). Because of the greater width of the incisor teeth in the upper jaw, the upper dental arch is more rounded in front and larger than the lower. In different persons there is considerable variation in the size and shape of the dental arches. This is chiefly in the curvature of the arch in front. Some are well rounded and broad, others are narrow and almost pointed, with many intervening variations.

The inner surface of the alveolar process of the upper jaw recedes from the necks of the teeth to merge with the lower surface of the hard palate (C, Figs. 122, 126, and 129). This slope is variable in the mouths of different persons and depends on the height to which the palate extends above the teeth. When the palate has a high arch, the inner surface of the alveolar process is more nearly parallel with the teeth than when the arch is low. Variations in palatal contour are illustrated in Fig. 131.

Alveolar abscesses around the apices of the teeth and pyorrheal infections around the necks of the teeth are foci from which infections may spread to more important structures. Such infected areas are so clearly indicated on Roentgen-ray films that roentgenograms of the teeth are an indispensable part of a thorough general examination of patients. While there are arguments supporting the

contention that all the teeth should be examined in this way, in many instances such a complete examination is not necessary. An examination by a competent dental surgeon, with roentgenograms of all crowned or filled teeth, spaces from which teeth have been extracted or are missing, and teeth around which a pyorrheal infection is suspected, is usually all that is required.

The number of films used in making a Roentgen-ray examination of the teeth differs in different laboratories. To show all of the teeth in their entire extent, at least eleven films are required (Fig. 118). Only in rare instances can all be included on ten films. In some laboratories, fourteen or more films are used in a full mouth examination. In that it gives more than one view of some of the teeth and does not require quite so careful technique, this larger number has certain advantages. Eleven films, properly exposed,

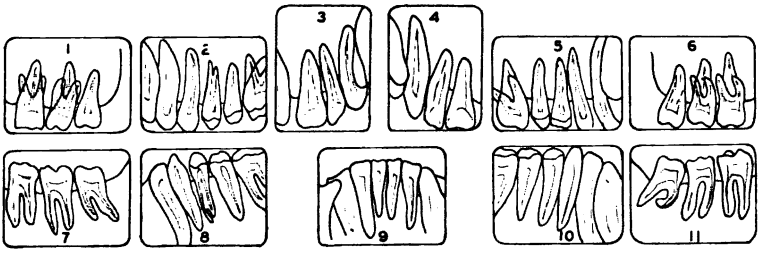

FIG. 118.—The teeth as shown on a set of eleven dental films.

are usually all that are essential. Should a more careful examination of any region or any particular tooth be necessary, additional exposures may be made. The eleven films are used, one for each molar region (Films 1, 6, 7, 11, Fig. 118); one for each canine and premolar region (Films 2, 5, 8, 10); one for the lower incisors (Film 9), and two for the upper incisor teeth (Films 3 and 4).

Except in the lower molar regions (C, Fig. 124), it is impossible to place a dental film parallel with the long axes of the teeth. The film must be placed against the soft tissues of the inside of the mouth and against the crowns of the teeth. In this position the roots of the teeth and the more deeply placed portion of the film will be separated by a considerable space, the plane of the film and the long axes of the teeth forming an angle. Because of this, it is impossible in dental roentgenography to direct the rays perpendicularly to the teeth or the film. They must be directed obliquely

through the teeth so that they strike the film at an angle. This causes distortion of the images on the films. The chief problem, therefore, is to direct the rays and expose the films so that this distortion will be reduced to a minimum, the images appearing as nearly as possible the exact size and shape of the teeth.

Dental films must be placed in the patient's mouth by the technician. Dexterity in this phase of dental roentgenography seems difficult for many persons to acquire and a lack of it is probably one of the factors that contribute to the prevalence of dental films of poor quality. Written instructions are far inferior to a demonstration, but by following those that are given in this chapter it is believed that skill may be acquired in this work.

No mechanical film holder has been invented that is as satisfactory for holding films in the mouth during exposures as the patient's

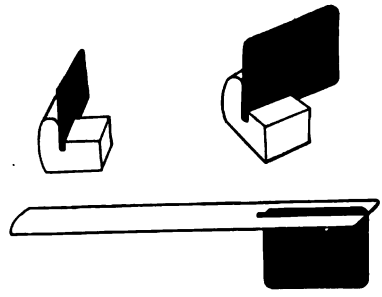

FIG. 119.—A block dental film holder and one made from a wooden tongue depressor.

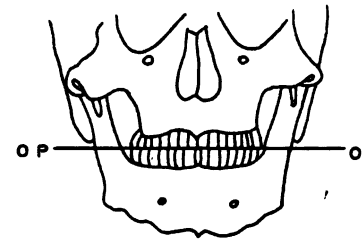

FIG. 120.—OP, the occlusal plane of the dental arches with the jaws closed.

fingers and thumbs. Films for the upper teeth should be held by the opposite thumb of the patient, the fingers of that hand being closed. Those for the lower teeth should be held in place by the index finger of the opposite hand with the palmar surface of the finger against the film, the elbow raised level with or above the head, and the thumb and other fingers closed. Because of stiff or painful joints or the absence of an extremity, occasionally some form of film holder must be used. The wooden block holder described by Sheldon and shown in Fig. 119 is a satisfactory form. The film is placed in the slit in the holder and put in place against the teeth, the patient biting on the projecting ledge. A simple device for this purpose that may be used in an emergency is a wood tongue depressor that has a narrow slot the length of a dental film cut in one end with a fine-bladed saw (Fig. 119). The film, fastened near one

edge in the slot, is placed in position, the patient holding it by biting on the projecting edge of the tongue depressor.

While dentists expose films of the teeth with the patient sitting and larger Roentgen-ray laboratories have dental chairs and special dental machines, smaller laboratories are not so equipped, the dental being but part of roentgenography done with a general purpose equipment. The technique here given primarily is intended for such a laboratory with the patient in the supine posture, but it can be adapted readily to the erect position and a special dental equipment.

The technical essentials that must be observed in roentgenography of the teeth may be grouped under four headings:

1. The position of the patient's head.
2. The position of the films in relation to the teeth.
3. The position of the Roentgen-ray tube and the angle of the incident rays.
4. The selection of the proper exposure factors.

THE POSITION OF THE PATIENT'S HEAD.

If a piece of cardboard be placed in the mouth in contact with the occlusal aspects of the teeth, it will lie in the occlusal plane of the dental arches. When the jaws are together, the occlusal planes of both dental arches will nearly coincide; but when the inferior jaw is open, there will be an angle between the occlusal planes of the upper and lower dental arches.

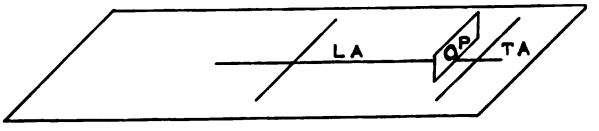

FIG. 121.—The correct position of the occlusal plane, OP, perpendicular to the table top and at right angles to its long axis, LA. The tube arm, TA, extends across the table also at right angles to the long axis of the table.

The occlusal plane, either of the upper or lower dental arch as the case may be, is a plane used to determine the position of the patient's head on the table. This plane (OP, Figs. 120 and 121) always should be perpendicular to the top and at right angles to the long axis or to the length of the table (LA, Fig. 121). The thickness of the pillow under the head should be adjusted with the idea of keeping this plane in its correct position. In exposing films of

different dental regions, the head will be turned on the neck, but the occlusal plane should be in the position indicated. When exposing films of the lower teeth, it is often necessary to elevate the chin to bring the occlusal plane into the proper position. Adjustment of the patient's head always should be done after the film is in place. If done before, the head may be disturbed by movement while placing the film.

The amount of rotation of the head on the long axis of the body, or the degree of turning of the head on the neck, varies with the region being examined. By studying the illustrations the proper position of the sagittal plane of the head and the films with reference to the plane of the table top can easily be learned. When the molar regions are being examined, the head is turned sideways so that the plane of the molar teeth is parallel with the table (A, Figs. 122 and 124). When the canine and premolars are being examined, the face is turned farther upward (A, Figs. 126 and 127), and when films of the incisor regions are being exposed, the nose and chin are directed upward (A, Figs. 129 and 130).

These instructions for the position of the head should be understood thoroughly and carefully followed, for their observance will greatly simplify the position of the Roentgen-ray tube and the angle of the rays, probably the most difficult detail of dental roentgenography.

THE POSITION OF THE FILM AGAINST THE TEETH.

The film should cover accurately the teeth to be exposed, overlapping them by a safe margin on both sides. It should be so placed that its edge or side will be parallel with the line of the crowns of the teeth with which it is in contact. If this is not done, the images of the teeth will extend obliquely across the film. The edge of the film need not correspond exactly with the occlusal plane of the teeth, but may projeet from $\frac{1}{8}$ to $\frac{3}{16}$ inch. This will insure that all of the crowns of the teeth will be on the film. If the film cannot be seen after it has been placed and the head adjusted, it is best always to run the index finger along the occlusal surface of the teeth and the edge of the film to make sure that it has not been displaced.

Certain regions present peculiar difficulties in the placing of the films. Those for the upper molar regions should not project farther forward than the middle of the second premolar tooth (B, Fig. 122). If this precaution be observed, there will be no danger of omitting

a part of the third molar tooth. Because of gagging, some difficulty may be experienced in placing films in this position. If care be taken to place the film as gently as possible without moving it over the palate into position, gagging usually will be prevented. When once begun, if the patient is instructed to take two or three quick,

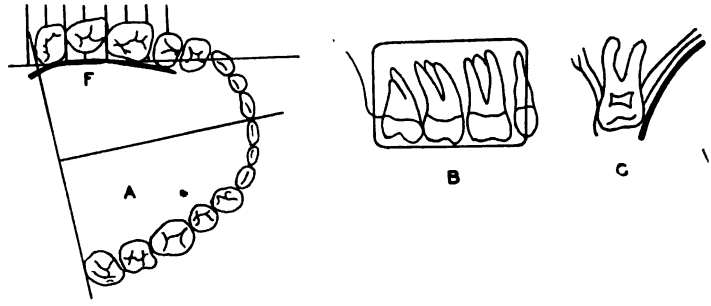

FIG. 122.—Position of the film for the upper molar teeth.

deep breaths through the open mouth, it may stop. In rare instances a patient will be encountered whose gagging reflex is so active that intraoral films cannot be taken without first anesthetizing the palate and pharynx.

In placing films for the upper molar teeth, turn the patient's head so that the teeth to be examined are uppermost, stand on the side of

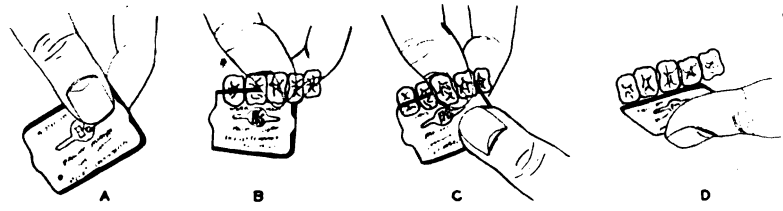

FIG. 123.—Placing the film for exposure of the upper right molar teeth. A, the film is grasped between the index finger and the thumb of the left hand; B, it is held against the occlusal aspect of the teeth extending backward from the middle of the second premolar; C, it is turned against the teeth by the patient's left thumb, guided by the right hand of the operator; D, it is held in position by the patient's left thumb.

the table facing the patient, grasp the superior anterior corner of the film (determined from the different aspects of the patient and not the technician) between the tips of the thumb and index finger of the opposite hand from the side of the patient being examined (left hand for right upper teeth, right hand for left upper teeth),

place the film in the patient's mouth with the inferior border along the occlusal aspects of the teeth from the middle of the second premolar posteriorly. At this step the film and teeth will form an angle of 90 degrees (B, Fig. 123). Then with the opposite hand guide the patient's opposite thumb into the proper position in the mouth, causing the patient's thumb to turn the film from the right angle position to the proper place alongside the teeth and lower part of the palate. If necessary, adjust the patient's head so that the occlusal plane is correctly placed and finally run the palmar surface of the index finger along the teeth and film margin to make certain that the film is correctly placed.

Films for the lower molar teeth must slip into the groove between the tongue and the gum (C, Fig. 124). If the tongue is retracted and the floor of the mouth relaxed, they can easily be slipped into

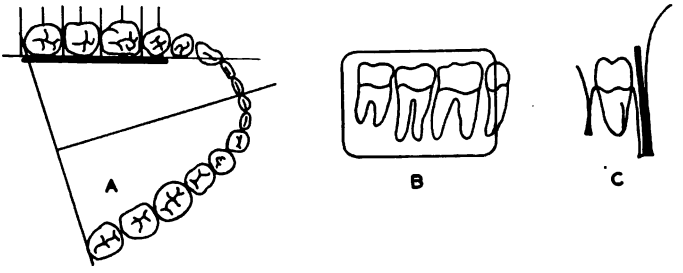

FIG. 124.—Position of the film for the lower molar teeth.

position. If the floor of the mouth is not relaxed, pressure of the sharp edge of the film against the rigid tissues will cause considerable pain. It is often necessary to explain and demonstrate what is meant by retracting the tongue and occasionally the tongue must be pushed downward and backward out of the way. The gum on the lingual side of the necks of these teeth forms a ledge-like projection which may catch the edge of the film. Should this occur, the film must be dislodged toward the tongue before being pushed deeper into the groove.

In placing films for the lower molar teeth, the technician stands as given above for the upper molars and holds the film between the index finger and thumb of the same side as that of the patient being examined (right hand for right teeth and *vice versa*). The film is placed in the mouth and inserted in the groove between the teeth and posterior part of the tongue. Then using both hands, the one

grasping the film and the index finger of the opposite hand, the film is gently worked downward in the groove into position. When in place, its anterior end is at the middle of the second premolar tooth. By holding the film with one hand the other may be used to guide the patient's index finger into place against the film (Fig. 125). The patient's elbow should be elevated as high as the mouth or higher, the palmar aspect of the finger should be against the film, and the finger far enough back in the mouth to prevent the film from turning so that its posterior part is displaced upward. If the patient swallows after the film has been placed, its position usually is disturbed and it must be replaced.

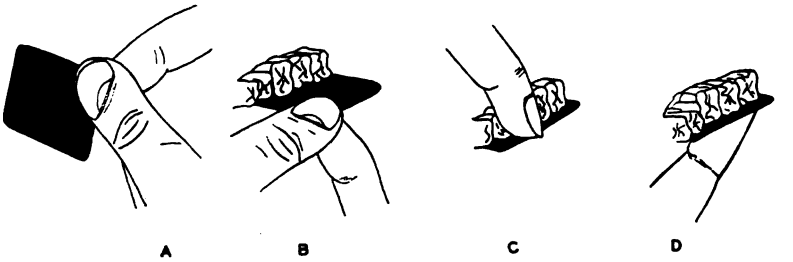

FIG. 125.—Placing the film for exposure of the lower right molar teeth. A, the film is grasped between the index finger and thumb of the right hand; B, it is inserted in the groove between the teeth and back of the patient's tongue; C, it is worked into position by the fingers of the operator and held by the index finger of the left hand; D, it is held in position for the exposure by the index finger of the patient's left hand.

If the jaw is short and a horizontally placed impacted third molar tooth is present, either partially or completely covered by the jaw and gum, it may be very difficult to place a film in the groove in a position that will picture the entire tooth. Such teeth are usually more on a line with the crowns than with the roots of the second molars, so that the placement of the film should be more backward than downward, even to the extent of having the film obliquely placed with the upper posterior corner higher than the occlusal surfaces of the teeth and with the other posterior corner covering the roots of the impacted tooth.

Because of the long roots of the canine teeth, the films for the canine and premolar regions, both upper and lower, should overlap this area more anteriorly than posteriorly (B, Figs. 126 and 127). They should come far enough forward to cover the lateral incisor and show at least a part of even the central incisors. Occasionally

a patient is encountered with such a sharp angle to the palate in front and such an acute curve in the upper arch that the upper canine teeth cannot be included on the same film with the premolars. A separate film then will be required for the complete delineation of each of the upper canine teeth.

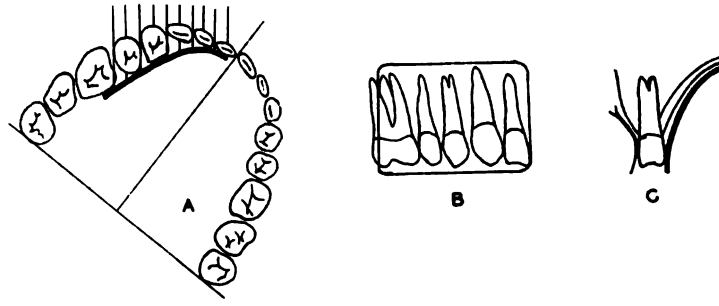

FIG. 126.—Position of the film for the upper canine and premolar teeth.

The placing of films for the canine and premolar teeth is not difficult. For those in the upper jaw, the technician stands facing the patient and holds the film by its upper anterior corner in much the same way as for the lower molar teeth on the same side. It is placed against the occlusal aspects of the teeth extending forward into the incisor region. It is held in position by the opposite thumb

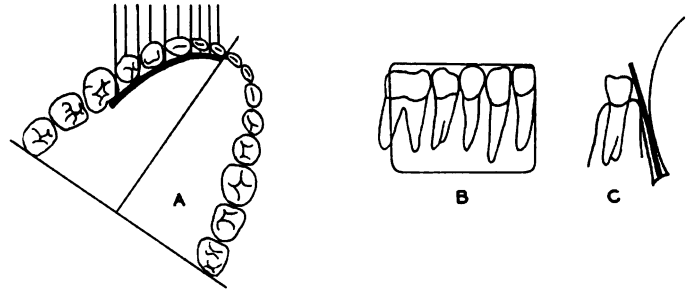

FIG. 127.—Position of the film for the lower canine and premolar teeth.

while the thumb that originally held it turns it into position and presses it against the palate and teeth. This hand is then used to guide the patient's thumb into position (Fig. 128). The maneuvers for placing films for the lower canine and premolar teeth are like

those for the molar teeth of the same side, making a separate description unnecessary. If the patient's finger is placed too deeply in the groove between the teeth and tongue when holding a film for

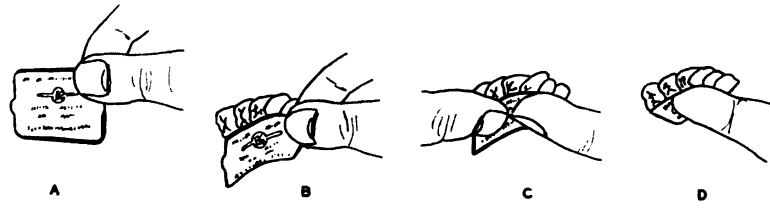

FIG. 128.—Placing the film for exposure of the upper right canine and premolar teeth. A, the film is grasped between the index finger and thumb of the right hand; B, it is held in position against the teeth; C, using both thumbs it is fitted against the teeth and palate; D, it is held in position for the exposure by the thumb of the patient's left hand.

the lower canine and premolar region, there is danger of the pressure of the finger sliding the film out of the groove. For this reason the

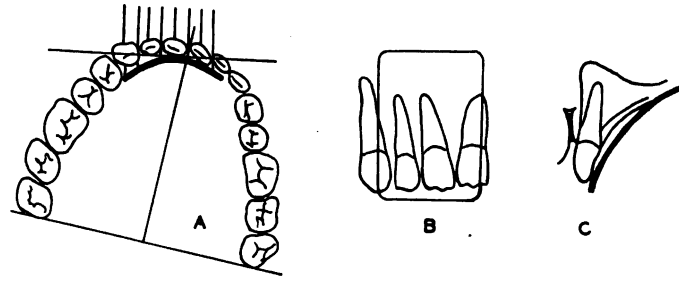

FIG. 129.—Position of the film for the upper central and lateral incisor teeth.

pressure should be such that it is against the crowns of the teeth or toward the bottom of the groove.

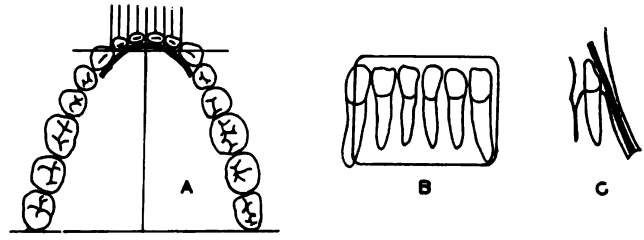

FIG. 130.—Position of the film for the lower incisor teeth.

Because of the width of the upper incisor teeth and the curvature of the jaw in that region, two films are required, one for the right

and one for the left teeth (Fig. 118). These are placed with their long axes parallel with the teeth, each so that it overlaps the opposite central incisor on one side and the canine on the other (B, Fig. 129). The lower incisors may all be shown on a single film (B, Fig. 130). It should be placed with an equal extent overlapping the lower incisor region on both sides.

Usually it is not difficult to place films for the incisor teeth. Directions given for other upper teeth should suffice for the upper incisors. For the lower incisor teeth, stand at the head of the table, facing the top of the patient's head. Before attempting to introduce the film, bend it over the finger to fit the curve of the teeth. Then grasp it between the index finger and thumb of the left hand, insert it into the groove with the aid of the opposite hand, and hold it with the left hand while the index finger of the patient's right hand is guided into position.

THE POSITION OF THE ROENTGEN-RAY TUBE AND THE ANGLE OF THE INCIDENT RAYS.

The rule that is usually given to govern the position of the Roentgen-ray tube and the angle of the central rays is: "The rays should be directed perpendicularly to a plane which bisects the angle formed by the plane of the film and the plane of the teeth." This rule is satisfactory when the film is not bent to fit the contour of the structures against which it is placed. Osgood emphasizes the necessity of having the film closely adapted to the palate in the upper jaw in order to secure the greatest detail on the films. He questions the advisability of following the rule and believes that the rays should be directed perpendicularly to the film through the apical region. Following his idea requires an angle of 45 degrees from the occlusal plane for the upper incisors and premolars and one of 35 degrees for the molars.

This question has been studied in detail. By carefully measuring the angles formed by the films and teeth and those of the tilt of the tube, it was found that the angle of tube tilt used is always from 5 to 10 degrees more than one-half that formed by the film and the long axes of the teeth. It was also found that Osgood's plan sometimes gives more shortening of the teeth than is considered best and does not provide for differences in the curvature of the palate in different persons. It is believed that the film should fit against the palate in the region of the apices of the teeth and that some allowance

should be made for different palatal curvatures that are encountered. For these reasons the following method of determining the angle of the incident rays is suggested.

The arm of the tube stand supporting the Roentgen-ray tube should extend directly across the table so that it and the side of the table are at right angles to each other (TA, Fig. 121). If this be done, and the occlusal planes of the dental arches are kept perpendicular to the table top and at right angles with its long axis as described under "Position of the Patient's Head," the primary tilt of the tube

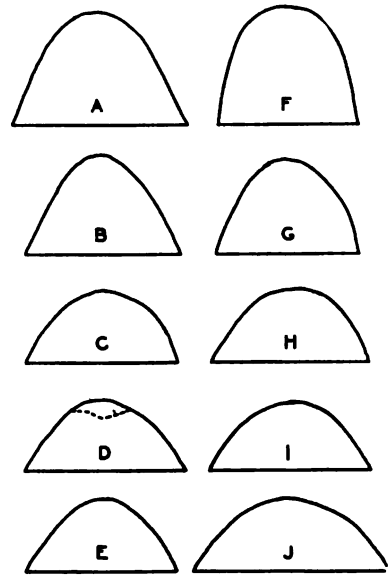

FIG. 131.—Variations in the contour of the hard palate. These curves were obtained by bending a thin strip of lead against the palate at the level of the space between the upper first and second molar teeth.

will be upward or downward, forming an angle with the occlusal plane either of the upper or lower dental arch as the case may be.

For the upper teeth, if these positions are maintained, the tilt of the tube and the angle formed by the central rays and the occlusal plane depend entirely on the curvature of the palate, both its height and the curve in the region in contact with that part of the film where the images of the apices of the teeth will fall. The tube tilt above the occlusal plane varies from one forming an angle of 20 degrees with the occlusal plane for a very high palate to one of 40

degrees for a low palate or one that curves abruptly near the top (Fig. 132). An angle of 30 or 35 degrees usually is correct, those of 20 and 40 degrees being required only for very high or very low palates. Figs. 131 and 132 show palatal curves, both average and extreme, and show necessary differences in the angles of the incident rays to compensate for the different curves. The tilt of the tube above the occlusal plane, when once determined, may be used for exposures of all of the upper teeth. Most tube stands are provided with a scale reading in degrees of a circle from which these angles may be read.

In this technique, the only feature that must be left to the personal selection of the technician and in which, therefore, there is something to be estimated or judged, is this curvature of the palate that determines the tilt of the tube and the angle of the central

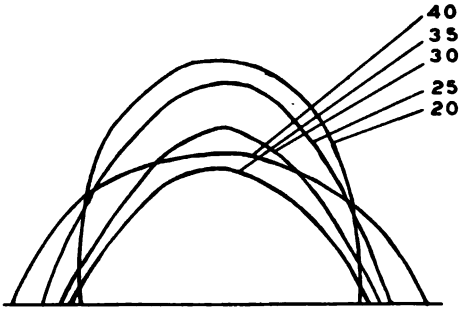

FIG. 132.—Showing variations in the angle of the incident rays depending on the contour of the palate.

rays. Since this is true, a technician should thoroughly familiarize himself with the variations in palatal contours. A strip of lead $\frac{1}{4}$ inch in width and 3 inches long may be bent so as to conform to the arch of the hard palate at the level of the space between the upper first and second molar teeth, and the curvature accurately determined. In this manner the curves in Figs. 131 and 132 were obtained.

Very little variation is required in the tilt of the tube below the occlusal plane of the lower dental arch for exposures of the lower teeth. If the angle formed by the occlusal plane and the central rays from the tube is between 30 and 35 degrees, it will be correct for all the lower teeth except the lower molars. This angle is required not because the bone recedes from the teeth as in the upper jaw, but when the film is held against the crowns of the

teeth the interposition of soft tissues in the floor of the mouth holds the films away from the apical regions of the teeth. The lower molar is the only region in the mouth where the films can be placed parallel with the teeth so that a tilt of the tube is unnecessary. In this region the rays should be directed perpendicularly to the teeth and the film.

A word needs to be said about the direction of the rays with reference to the teeth themselves. In all but the canine and premolar regions the rays should be directed so that they pass through the proximal spaces between the teeth. For the premolar and canine teeth, the greater length of the canine requires that the rays be directed slightly backward, more through the apex of the canine than directly through the interproximal spaces. This should not be enough to cause the images of the teeth to be superimposed but it is enough to distort the images of these teeth more than would occur if the rays passed directly between them. If the direction of the rays and rotation of the head shown in Figs. 126 and 127 are closely approximated and if the film overlaps farther anteriorly than posteriorly, the direction of the rays will be correct.

Occasionally patients are encountered whose heads cannot be placed in the proper position. These are corpulent persons with short thick necks and those suffering pain from a neuritis or other conditions in the neck and shoulders. With them the difficulty will be in turning the head far enough sideways to have it in the proper position for the exposure of the posterior teeth with a single tilt of the tube. When this happens, the deviation of the head from the proper position must be compensated for by also tilting the tube toward the face. If this be required, the tilt should be such that, except for the upper canine and premolar teeth, the rays pass directly through the proximal spaces between the teeth.

EXPOSURE FACTORS.

The Roentgen-ray tube used in dental roentgenography should have a reasonably small focal spot. The 10- and 30-milliampere and 5-100 radiator types or the fine focus universal tube should be used. The 10-milliampere radiator or the special dental and oil immersed tubes usually are used with extra-fast dental films with which the exposure must be very exact. Radiatized or regular films have considerably more latitude in their exposure. With tubes having a fine focal spot, a long anode-film distance is not necessary.

With the end of a small cone or a special dental cone from 2 to 3 inches away from the face, the distance will be about 16 inches.

In exposing dental films a relatively high milliamperage, a moderately long exposure, and a low voltage will give the best results. Using factors of this kind, trial exposures may be made, the films given a standard development, and the most suitable factors selected.

A set of factors that has given uniformly good results is as follows: anode-film distance, 16 inches; milliamperes, 30; four seconds time for the molar teeth and three for the others, with a different voltage for each of the kinds of dental films. With Eastman regular and Buck X-Ograph films the voltage is the same as that for 20 centimeters of thickness from the thickness-voltage chart given in the basic technique (Fig. 40), for extra-fast films the voltage is the same as that for 12 centimeters, and for Eastman radiatized films the voltage is the same as that for 16 centimeters from the chart.

These factors may be kept constant for almost all patients. When examining an individual with unusually heavy and thick jaws, it is occasionally advisable to add 2.5 peak kilovolts to the voltage, or with children and thin-jawed persons or for edentulous areas, to decrease the voltage by 2.5 kilovolts. The permissible variations in exposures compensate for the usual variations in the thickness of the jaws, etc.

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CHAPTER XVII.

THE THORACIC VISCERA.

THE thoracic viscera may be divided into two groups; in one are the pleural membranes and the lungs and the other includes those structures which form the mediastinum. Structures in the mediastinum of roentgenographic importance are the heart and thoracic aorta, the pericardium, the esophagus, and the thymus gland. In some instances the mediastinal lymph nodes require consideration.

The lungs are elastic, air-filled organs accurately filling the space in the thoracic cavity on each side of the mediastinum. They project for a variable distance above the clavicles into the neck. At their bases they are in contact with the upper surface of the diaphragm which separates the right lung from the liver and the left from some of the abdominal viscera, chief of which is the fundic portion of the stomach. Since the liver rises higher than the stomach, it follows that the right arch of the diaphragm and hence the base of the right lung is higher than the left, making the right the shorter lung. Because that part of the mediastinum occupied by the heart and pericardium bulges farther into the impression in the left than it does into the right lung, the left is narrower and smaller than the right. Except at the roots, each lung is covered by a double layer of pleural membrane that permits of movement of the lungs in the expansion and contraction of the thorax.

The largest and most important constituents of the mediastinum are the heart and aorta. The heart within the pericardium makes up the inferior and anterior part of the mediastinum and extends laterally beyond the limits of the other structures to fit into impressions in the lungs. Like the lungs, the heart is covered with a double layer of serous membrane, the pericardium, which permits of its movement on surrounding structures. From the base of the heart the aorta extends upward, arches backward and slightly to the left along the side of the body of the fourth thoracic vertebra, then turns downward behind the root of the left lung and in front of the esophagus to leave the thorax through the aortic opening in the diaphragm.

The esophagus is the most posterior of the mediastinal structures. It enters the thorax at the inlet above and extends through its entire length, lying just anterior to the thoracic vertebræ (Fig. 143). In its upper part it is located in the midline, deviating slightly to the left in its lower extent. The trachea is located anterior to the esophagus in the upper part of the thorax. It extends from the inlet as far as the fourth thoracic vertebra, where it divides into the two main bronchi which almost immediately become constituents of the lung roots. The thymus gland is located in the upper part of the anterior mediastinum. Except in infants and young children, it is never of large size nor of clinical importance. The mediastinal lymph nodes, most numerous around the trachea and bronchi and extending lateralward into the lung hiluses, are never of roentgenographic importance unless considerably enlarged.

There is quite a variation in the shape of the bony wall of the thorax and of the thoracic viscera which is not due to differences in the size of different individuals. On the contrary, it is due to differences in body architecture, for which the general term habitus, meaning body shape or appearance, is used. Mills has attempted to classify the habitus of a large number of persons and to point out the differences in the body shape and the shape of the viscera in the various types. He recognizes two dominant types, four major types, and a number of sub-types (Fig. 138). The two dominant types are the hypersthenic and asthenic. An individual of the hypersthenic habitus is one with a massive and powerful physique, of great body weight, and with a heavy bony framework. The thorax is short, wide, and deep. The ribs are directed more nearly horizontally than in any other type. The subcostal angle is obtuse and the xyphoid cartilage is broad. The lungs are widest and bulkiest at the base and contracted at the apices. They project but little above the clavicles into the neck. The arches of the diaphragm are high so that much of the lungs is located behind and below the highest parts of the diaphragm. The long axis of the heart is nearly transverse to that of the body and part of the heart is often below and behind the highest part of the diaphragm (Fig. 139).

An individual of the asthenic is the antithesis of one of the hypersthenic habitus. The body is frail and slender, light in weight, with delicate bones. The thorax is long and narrow (Fig. 138). There is a marked downward slope to the ribs. The subcostal angle is acute. The lungs are widest in their upper zones and reach well above the clavicles into the neck. The diaphragm slopes downward.

The heart is pendant, with its long axis nearly vertical and near the midline, a condition too often called a "drop" heart. Practically all of the lungs and the heart are located above the highest limits of the diaphragm (Fig. 139).

Not many belong to the two dominant types of body habitus. Most individuals are between these two extremes. If a large number of persons be arranged according to the type of habitus, from the hypersthenic at one extreme to the asthenic at the other, probably all degrees of variation will be found. It is important in visceral roentgenography to keep in mind the variations in habitus with the differences in the shape and position of the viscera directly traceable to them.

THE LUNGS AND PLEURÆ.

Roentgenologic examination is of the utmost importance in detecting the presence and extent of disease within the lungs. To enumerate the conditions in which it is useful would be to make a list of the diseases of the lungs in which there are macroscopic pathological changes.

Roentgenologic examinations of the lungs should be both fluoroscopic and roentgenographic; the first to study thoracic expansion, illumination of the lungs on deep inspiration and after coughing, to determine, if possible, the character of gross pathological changes, and to observe the thoracic viscera from different angles; the second to register on the films the shadows of pathological changes of all sorts so that they may be studied and preserved for comparison with those of later examinations. While gross lesions in the lungs often can be identified with the fluoroscope, it should never be depended on in searching for early tuberculous infection nor to furnish the details of any type of pathological process.

Roentgenograms of the lungs and pleuræ may be made in either the antero-posterior, the postero-anterior, right or left lateral, or oblique directions. The most useful of these views and the one most often taken is in the postero-anterior direction, with the cassette and film along the front of the chest and the tube at the back. This position brings the heart closest to the film, thus giving the least distortion of its image; since the anterior part of the chest wall is thinner than the posterior, it brings the lungs slightly closer to the film and it enables the shoulders to be rotated forward around the thorax, projecting the shadows of the scapulæ laterally away from those of the lungs. Either the erect or prone position may be used.

Antero-posterior views should only be taken when the patient is too sick to be turned to the prone position.

Evans, LeWald and Green, Pritchard, and Chapman emphasize the importance of lateral and oblique roentgenograms of the chest. They are of unquestioned value in the location in the antero-posterior direction of isolated pathological lesions of relatively large size, such as lobar pneumonias, lung abscesses, pulmonary cavities, interlobar accumulations of fluid, etc.

There is considerable difference of opinion whether films of the lungs should be made stereoscopically or not. Dunham and others emphasize the importance of stereoroentgenograms. Chapman says that at the Stanford Medical School stereoscopic films are not made as a routine, but, in addition to the postero-anterior view, a lateral film is taken. Holmes and Ruggles say that stereoscopic films are not necessary as a routine procedure, while Wessler and Jaches emphasize the greater importance of a good single plate or film in preference to a mediocre stereoscopic set. Unquestionably the contention of Wessler and Jaches is true, yet stereoscopic films of good quality are preferable to a single film of equal quality, particularly in examining for early tuberculosis and for one who has not learned the ramifications of the different markings as seen on single films from a study of stereoscopic pairs. In the examination of gross lesions a postero-anterior and a lateral film probably are preferable to a single stereoscopic pair.

Since the horizontal position causes engorgement of the pulmonary vessels and interferes with respiration, postero-anterior films of the lungs, whenever possible, should be taken with the patient in the erect position, either sitting or standing. This is especially important in examining those who have a protuberant abdomen. If the abdomen is at all large, placing the patient in the prone position will force the abdominal contents and fat into the lower part of the bony thorax and elevate the diaphragm, thus diminishing the expansion of the thorax and the parts of the lungs that will be shown on the film above the diaphragm. The erect position necessitates a device to support the cassette while the exposure is being made. Any one of the vertical stereoscopic plate changers, or even a home-made device that may be raised and lowered, will serve for this purpose.

In exposing such films, the cassette is placed in the holding device and adjusted so that the extended chin just reaches the top of the cassette. The tube is turned so that the rays are directed

horizontally. The patient is placed in front of the cassette with the chin elevated, the palms of the hands on the greater trochanters of the femora, with the elbows bent, and with both shoulders rotated forward until the elbows and the shoulders touch the cassette or cassette holder (Fig. 133). The shoulders should also be depressed as much as possible, which will depress the clavicles and prevent their shadows from crossing the apices of the lungs. A band that may be fastened across the patient's back to assist in immobilization is of considerable value. The anode of the tube should be at the

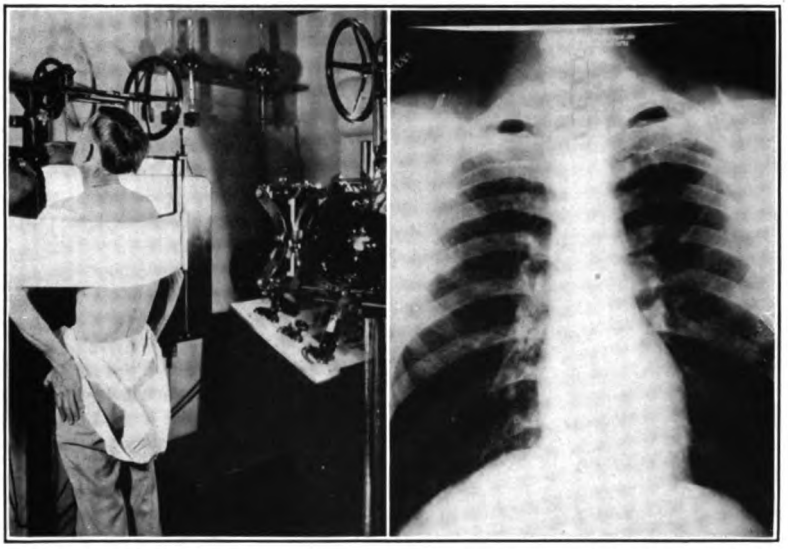

FIG. 133.—Single or stereoscopic postero-anterior exposure of the lungs with the patient erect. The shoulders are rotated forward and depressed; the rays are directed horizontally through the fifth or sixth thoracic vertebra.

height of the patient's fifth or sixth thoracic vertebra, directing the rays into the thorax at this level. A full inspiration— not the fullest that the patient can take, but the fullest that does not cause straining—should be taken and held while the exposure is being made.

This position is also used for stereoscopic postero-anterior films of the lungs. The patient takes this position in front of the automatic plate changer, takes a full inspiration, the first film is exposed, the films are changed and the tube is shifted, then the second film is exposed, all of this taking place while the patient holds the breath and remains immobile. The tube shift should be in the vertical

direction, the amount of shift depending on the anode-film distance (page 179).

The position of the film and patient for postero-anterior films in the prone position should be the same as that for the erect position. The chest is placed on the cassette, the chin extended so that it is just off the top of the film, the upper extremities are placed at the sides, and the shoulders dropped forward and depressed (Fig. 134). The exposure is made at full inspiration. Films in the lateral posi-

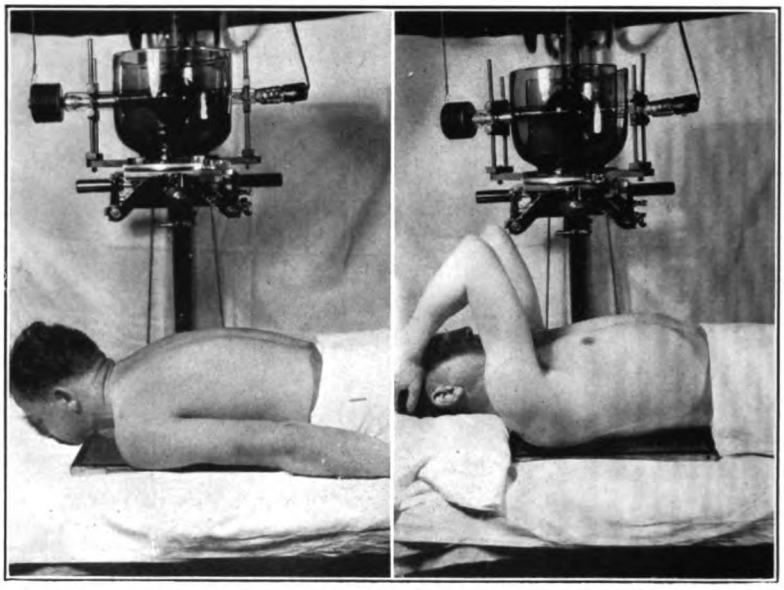

FIG. 134.—Positions for exposures of the lungs with the patient horizontal. On the left, the position with the patient prone; on the right, with the patient supine. The erect position (Fig. 133) is the best. The prone position may be used when the patient is unable to stand, the supine position being used only with those patients who are unable to stand and are too ill to be turned to the prone position.

tion should be exposed with the patient lying on the side which contains the pathological lesion being studied. By placing both upper extremities above the head more of the lung fields will be uncovered by the shoulders than in any other position (Fig. 85). In exposing films in the supine position, clasping the hands behind the head and bringing the elbows forward over the face as far as possible will rotate the scapulæ forward so that their shadows will not cover a part of the lung fields (Fig. 134).

The kind of roentgenologic examination that should be made of a

given patient depends largely on the condition of the patient and the type of disease that is present. In an office practice where almost all patients are ambulatory, a fluoroscopic examination in the erect position should first be made. If marked evidences of disease are found, a single film in the postero-anterior direction with the patient in the erect position should then be taken. If no lung involvement is seen with the fluoroscope, and, as is so often the case, the examination is being made to detect or eliminate a tuberculous infection, postero-anterior stereoscopic films in the erect position should be taken. When dealing with those that are acutely ill and unable to stand, fluoroscopy may be performed with the patient in the supine position. Since incipient pulmonary tuberculosis is rarely sought under such conditions, single films in the supine or prone position may be taken. If a gross pathological lesion is found in one side, considerable diagnostic information can often be obtained from a lateral or oblique view of the thorax. The best position for this view may be determined during the fluoroscopy. The patient should be in the same position relative to the film that showed the lesion best with the fluoroscope, the cassette and film replacing the screen in each instance, with the involved side nearer the cassette. In seeking a fluid level in a suspected hydropneumothorax or lung abscess, a postero-anterior film with the patient in the lateral position may be made by placing the cassette against the front of the chest and directing the rays horizontally. For such views the side in which the disease is located should be uppermost.

All views of the lungs of adults should be made on 14- by 17-inch films. Those of children may be made on smaller films.

THE HEART AND AORTA.

Roentgenologic examinations of the heart and aorta should be, like those of the lungs, both fluoroscopic and roentgenographic. The position, shape, relative size of the whole heart and of the different chambers, the cardiac contractions, and the size and position of the aorta, can be observed with a fluoroscope in different directions and for a considerable period of time. With certain types of fluoroscopes or with special attachments that may be fastened to other kinds, orthodiagraphic tracings of the cardiac outlines, giving nearly the exact dimensions of the heart shadow, can be made. Orthodiagrams serve the same purpose as teleoroentgenograms in

determining cardiac size and shape. Such work should, of course, be undertaken only by those who are familiar with the normal and abnormal appearance of these structures and who have acquired skill by study and practice in this kind of an examination; ordinarily it is work not belonging within the province of the Roentgen-ray technician.

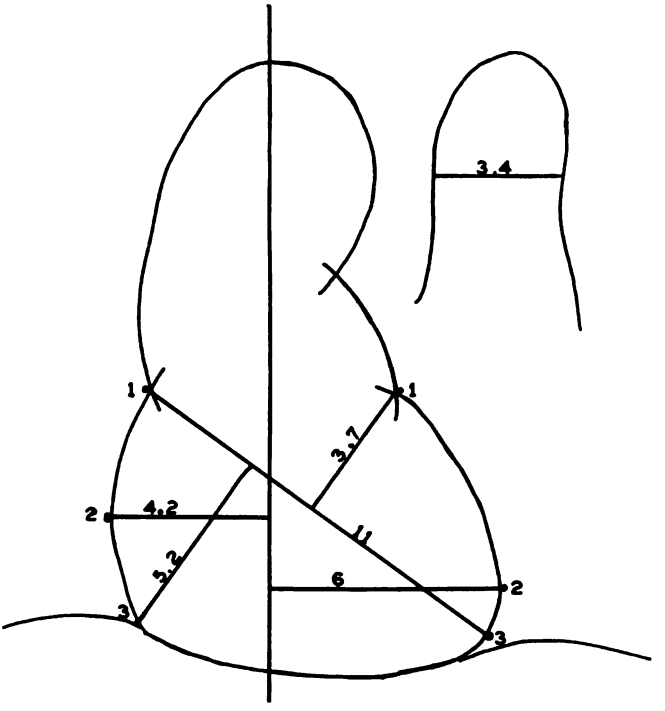

FIG. 135.—Orthodiagram of the cardiac shadow made with an attachment for a vertical fluoroscope.

Roentgenography of the heart is limited in its usefulness to determining the size and shape of the heart from measurements of the cardiac shadow. If films of the thorax in the postero-anterior direction are exposed with an anode-film distance of 6 feet or more, with the patient standing or sitting, teleoroentgenograms are made which show the size of the cardiac shadow with but little distortion. From these the measurements of the different diameters and the total area may be obtained, from which, when compared with figures given in tables of known normals, the presence or absence of cardiac enlargement may be determined. If changes in shape

should also be present, these can be detected, and when characteristic of some definite organic lesion, they assist in making diagnoses of cardiac diseases. In studying cardiac shape the variations incident to variations in body habitus should be remembered.

The method of examination of the heart in use at the Massachusetts General Hospital and described by Holmes, and by Holmes and Ruggles, is one that can be used in any Roentgen-ray laboratory equipped with a vertical fluoroscope, and is one that gives much of the information needed. This consists of a fluoroscopic examination and a teleoroentgenogram. The fluoroscope is arranged so that there is a distance of 24 inches between the tube anode and the screen. Enough voltage and milliamperage is sent through the tube to give a good image on the screen. The patient is placed directly behind the screen which is fixed in position. A thin glass plate or piece of cleaned Roentgen-ray film is placed on the screen and a tracing of the heart and great vessels is made during quiet respiration. Tracings are also made of the excursion of the left border of the heart and diaphragm during forced respiration (Fig. 136). The patient is then turned to the left, with the right side of the chest against the screen. In this position the arch of the aorta is seen in profile. When the patient is in the position that gives the narrowest shadow, a tracing of the aorta is made. The glass or film is then removed and the fluoroscopic examination of contraction, etc., completed.

Before the patient leaves the fluoroscope, a mark is placed on his body opposite the center of the cardiac shadow. This serves as a mark to determine the height of the Roentgen-ray tube and a spot upon which the tube is centered in making the teleoroentgenogram. For the film, the patient is placed in front of the vertical plate changer or other cassette-holding device in much the same position as for a film of the lungs. The rays should pass through the heart at right angles to its transverse diameter; a slight rotation of the patient will considerably distort the shadow. The patient need not suspend respiration during the exposure; it is sufficient for him to remain immobile, breathing quietly. Exposures long enough for the heart to complete at least one cycle, so that the shadow will be that of the heart in diastole, should be used. If a pericardial effus on is suspected, since the fluid will change in the change of position of the patient's body, thus changing the shape of the cardiac outline, a film is exposed in the prone position also.

When the film is dry, three points are marked on each side of the

cardiac outline (Figs. 135 and 137). On the right side these are: (1) At the junction of the shadow of the right auricle with that of the great vessels. (2) The point of the heart shadow that reaches farthest to the right. (3) The junction of the heart shadow with that of the diaphragm. On the left side these are: (1) The junction of the left auricle with that of the left ventricle. (2) The point of the

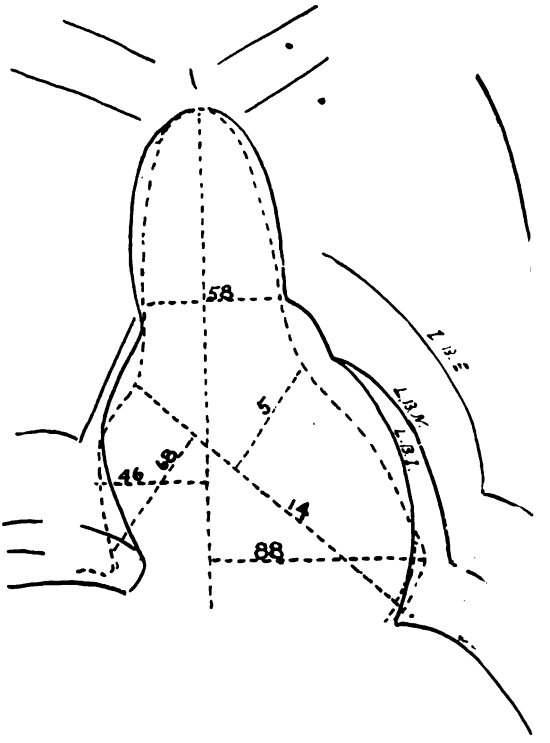

FIG. 136.—Tracing of the heart showing the cardiac size and shape and the normal respiratory excursion of the heart and diaphragm during quiet and forced respiration, with the patient standing. (Holmes and Ruggles.)

heart shadow farthest to the left. (3) The apex of the heart. A line drawn through the middle of the vertebral column is used as a median line. With these points as guides the various measurements are made. From the median line at right angles to the points farthest to the right and to the left gives the transverse diameter. From the highest point on the right to the apex constitutes the longitudinal diameter, while the sum of measurements at right angles

from the longitudinal diameter to the highest point on the left and lowest point on the right gives the diameter of the base. For comparison with those determined during the examination, the

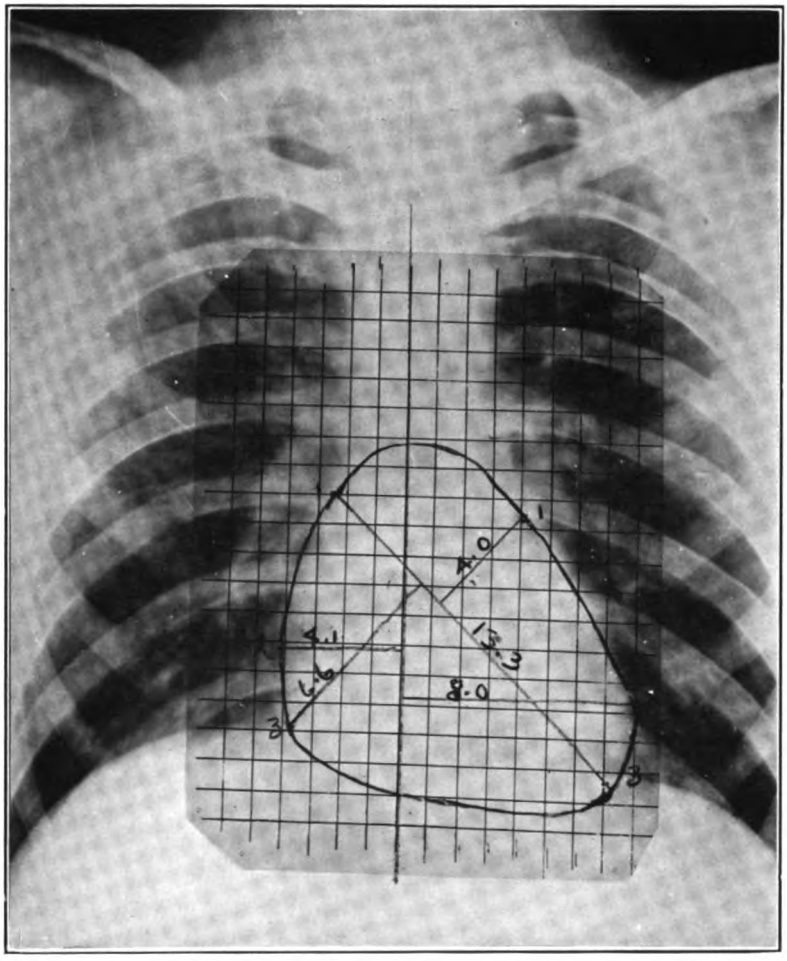

FIG. 137.—Teleoroentgenogram of the heart showing the method of making measurements of the diameters and of the total area of the cardiac shadow by means of a cleaned Roentgen-ray film ruled in square centimeters.

normal measurements may be obtained from Claytor and Merrill or from either of the three editions of Holmes and Ruggles.

A different method of determining heart size was adopted by the cardiovascular service of the army during the World War. It was

based on the work of Bardeen, who made measurements of the total area of the cardiac silhouette. This method is given in the United States Army *X*-ray Manual, page 412. The total area of the shadow is determined from a teleoroentgenogram made in the manner described above, using a distance of 6 feet, with the sternum flat against the cassette, and the central rays directed through the ninth thoracic vertebra. The heart outline is completed by extending the line for the right and left margins across the base of the great vessels, around the apex and across the diaphragm (Fig. 137). The area thus outlined is measured with a perimeter or by means of an area ruled in square centimeters. If the latter is made on a piece of cleaned Roentgen-ray film it may be placed over the film and the heart area determined by counting the whole squares and estimating the fractions (Fig. 137). The variations from normal, if any, are determined from the tables for normals of individuals of different height and weight prepared by Bardeen.

The aorta may be studied both with the fluoroscope and on films. In the postero-anterior direction the ascending aorta overlaps to a variable extent the beginning of the descending thoracic aorta. The diameter of the aortic arch is best seen in right oblique views of the chest. The ascending aorta and the arch are best seen in left oblique views. No particular position of the patient will be correct in all instances for roentgenograms of the aorta. A good procedure is to determine by fluoroscopic examination the position of the patient that gives the desired view of the aorta, then to place the patient in this position for the exposure of the film. By arranging the patient in the same position before a vertically-placed film that he occupied behind the screen of the fluoroscope, similar images will be obtained.

THE THYMUS.

The thymus is frequently enlarged in infants and young children, causing interference with respiration and swallowing. Many cases of sudden death of children during anesthesia, usually for the removal of tonsils and adenoids, have been attributed to an enlarged thymus. Roentgenograms are required for detecting this condition. These may be made in either the supine or prone position. The prone position is the better one. Since these patients are not coöperative and are often intractable, considerable persistence and patience are required, even to the making of several exposures, before a satisfactory film is obtained.

The patient should be stripped and placed as nearly as possible in the prone position with the chest on an 8- by 10-inch cassette. It is usually necessary to hold the arms, legs, and head. Care should be exercised to have the chest and head in a symmetrical position, for direct postero-anterior views without rotation are the most satisfactory. Since the thymus is larger, probably from engorgement, when the child is crying, the louder the child cries the better. Each cry is followed by a deep inspiration. At the beginning or ending of each cry there is a momentary period during which the breath is held. This is long enough to make a one-tenth-second exposure. A distance of at least 35 inches should be used.

Remer and Belden obtain postero-anterior views by having the child held erect by the nurse with the thumbs holding the cassette and the fingers holding the child's shoulders against the cassette. They emphasize the importance of making the exposures during crying, and make two views, one at the end of inspiration and one at the end of expiration.

The examination of the esophagus, a part of the alimentary canal, will be discussed in the next chapter.

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CHAPTER XVIII.

THE GASTROINTESTINAL TRACT.

UNDER the heading of gastrointestinal tract will be considered all parts of the alimentary canal—the esophagus, stomach, small and large intestine, and appendix—and the gall bladder and liver.

Except the esophagus, all of these structures are contained within the abdomen, a part of the body the characteristics of which depend, possibly even more than those of the thorax, on the body form or habitus of the individual. Upon habitus also depend variations which are often quite pronounced in the shape, position, size, tonus, and activity of the different parts of the alimentary canal, variations with which the technician should be familiar.

Referring again to Mills' two dominant types, the hypersthenic and asthenic, marked differences in the abdomen are found in these two forms (Figs. 138 and 139). Persons of the hypersthenic habitus have a long abdomen with the greater abdominal capacity in the upper part, the pelvis being relatively small, and occupied by extraperitoneal fat. In general, in this type, the greater upper abdominal capacity, with the large amount of omental and extraperitoneal fat and the greater tonus of the anterior abdominal muscles, is responsible for a high position of all abdominal parts of the alimentary canal.

Contrasted with this, individuals of the asthenic habitus have a short abdomen with the greater abdominal capacity in the lower part, that of the upper part being relatively small. The usual absence of abdominal fat and the lessened tonus of the abdominal muscles with the greater capacity in the lower part are responsible for the relatively low position of parts of the alimentary tract.

As stated in the discussion of the effect of habitus on the thoracic viscera, only a small percentage of individuals belong to these two extreme types; others present some intermediate form of which all possible gradations are encountered. Corresponding closely to the differences in habitus are equal and just as striking normal variations in the form, position, tonus, and motility of the abdominal parts of the alimentary canal.

For example, the stomach of a person of the hypersthenic habitus is steerhorn shaped and high in the abdomen (Fig. 140). The fundic portion, located under the left arch of the diaphragm, is the

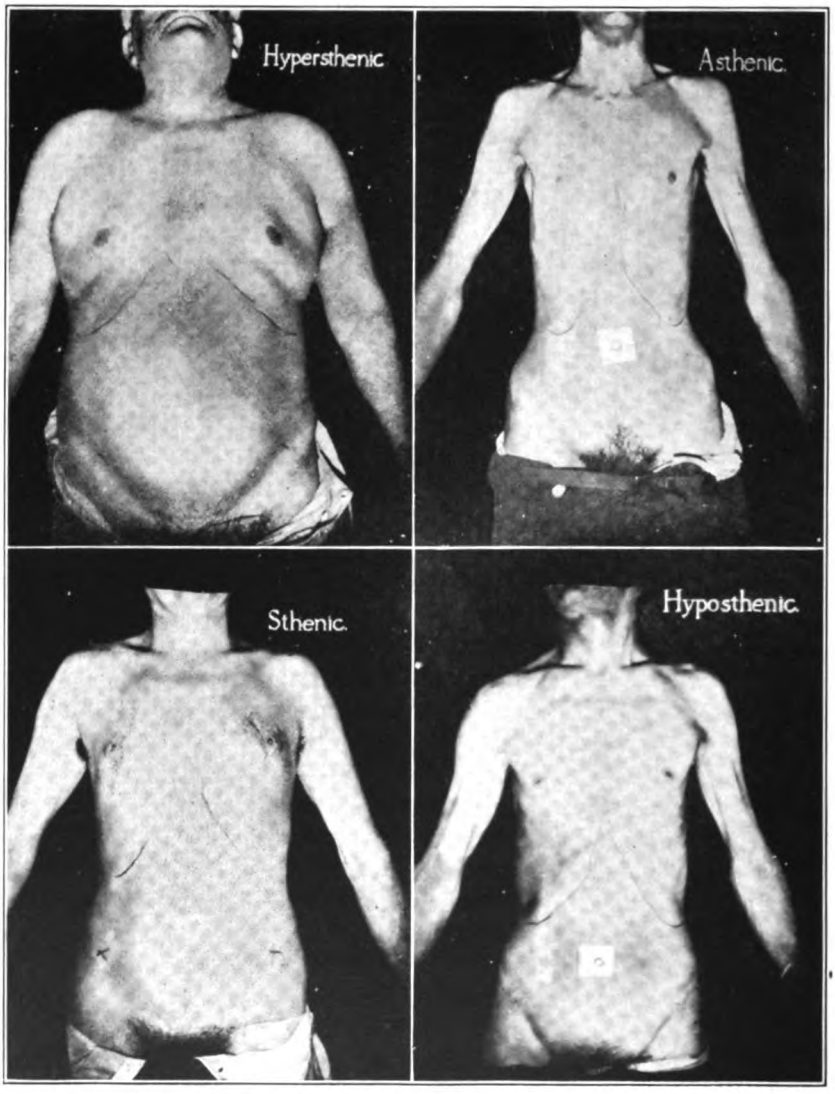

FIG. 138.—Photographs of types of bodily habitus. (After Mills. Reproduced through the courtesy of the American Journal of Roentgenology and Radium Therapy.)

widest part. From the fundus, the body and pyloric portion extend obliquely downward and toward the right across the upper part of the abdomen above the umbilicus. The pylorus is the most dependent portion, the duodenal bulb being located at the level of the

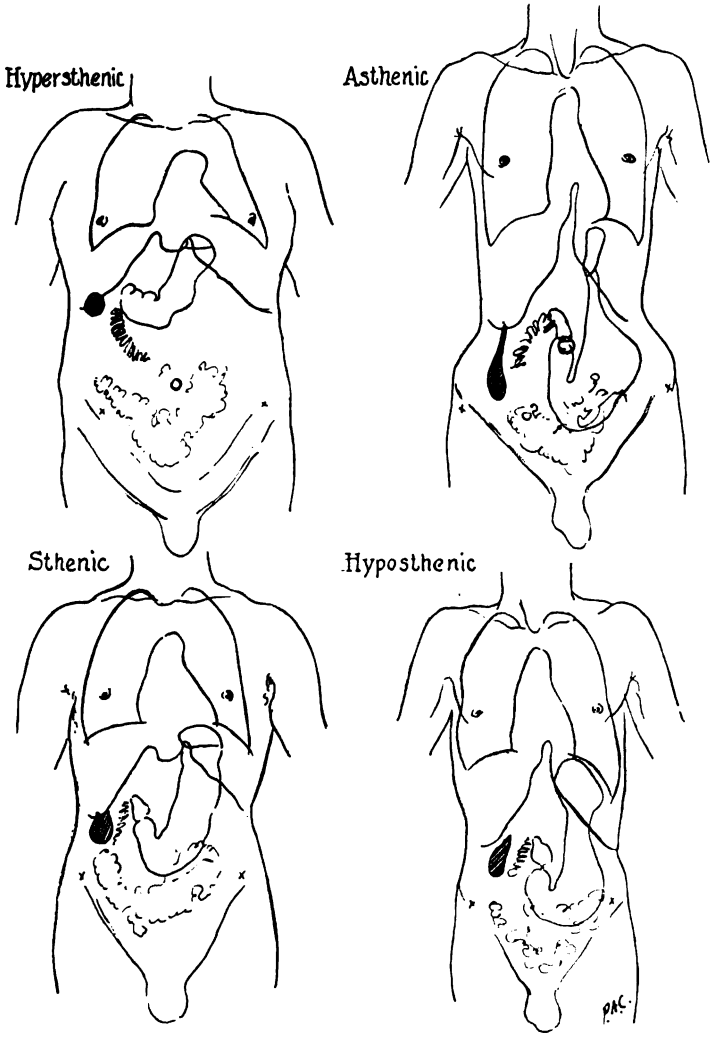

FIG. 139.—Diagrammatic representation of bodily habitus, including form and position of some of the thoracic and abdominal viscera. (Modified from Mills and reproduced through the courtesy of the American Journal of Roentgenology and Radium Therapy.)

pyloric sphincter or slightly lower. In a stomach of this form tonus is good and peristalsis active, as a result of which emptying is rapid.

The stomach of a person of asthenic habitus, to correspond to the body form of the individual, is, when filled, of a fishhook shape with the most dependent portion of the greater curvature below the umbilicus (Fig. 140). The fundic portion is located in the left arch of the diaphragm from which the stomach passes vertically downward for a variable distance in the left side of the abdomen, to curve to the right across the vertebral column, finally to pass upward to terminate in the pylorus on the right side of the second, third, or fourth lumbar vertebra. The pylorus is always higher

FIG. 140.—Variations in the shape and position of the filled stomach as shown on films exposed in the prone position, depending largely on variations in bodily habitus. The upper left figure is reduced somewhat more than the others; the reduction in the size of the others is uniform. The position of the umbilicus is indicated by a black or white spot.

than the most dependent portion of the lesser curvature. The tonus of the musculature of such a stomach is diminished, peristalsis is limited to the prepyloric portion, the waves being infrequent and slowly moving; the emptying is slow.

Most persons, being intermediate in habitus between the hypersthenic and asthenic, have stomachs intermediate between these two forms. Moody, Van Nuys, and Chamberlain have made a careful examination of the position of the stomach in 1000 healthy young American adults, an equal number of males and females, none of whom gave a history of digestive trouble. They made roentgenograms of the stomach when filled with a barium meal weighing

slightly more than 1½ pounds, with the subjects in the erect position. A line connecting the highest points of the iliac crests, which is slightly below the usual position of the umbilicus, was used as a level from which to measure the position of the viscera. They found in 25 per cent of the males that the greater curvature of the filled stomach was located above the line, 51.8 per cent in the first 2 inches below the line, and 23.2 per cent still lower in the abdomen. In the female subjects the stomachs were somewhat lower; 11.6 per cent were located above, 45 per cent in the first 2 inches below, and 43.4 per cent lower than 2 inches below the interiliac line. These figures give a very good idea of the position and consequently the shape of the filled stomach in both males and females when examined in the erect position.

The variations in position of the small intestine have not been so extensively studied as have those of the other abdominal viscera. Just recently, Morse and Cole described a method of examining the small intestine with Roentgen-rays, but no extensive studies in healthy persons have been attempted. It is quite probable, however, that this part of the intestinal tract shares in the variations in position common to the stomach and large intestine.

The position of the duodenum varies in much the same manner as does that of the stomach. The first portion, called by roentgenologists the duodenal cap or bulb, which is functionally and developmentally a part of the stomach, varies in position, depending on the type and location of the stomach to which it is attached. Its range of positions is along the anterior aspect or to the right, occasionally to the left, of the first, second, third, and fourth lumbar vertebræ; highest in connection with stomachs of the steerhorn shape in the hypersthenic and lowest with the so-called atonic stomachs in the asthenic (Fig. 140). The duodeno-jejunal flexure, supported by the suspensory muscle of the duodenum (ligament of Treitz), is as constant in its position to the left of the second lumbar vertebra as any part of the intestinal tract. In persons with low stomachs, the flexure is often seen at a level higher than the lesser curvature. With one end of the duodenum relatively constant in position and the other end variable, the duodenum presents quite a variety of different shapes and positions. The shape is usually like the letter C, V, or U with the opening directed upward and toward the left.

Little need be said about the remainder of the small intestine. As a rule, from the duodeno-jejunal flexure the coils of small intestine are arranged from above downward in the left side of the

abdomen, sometimes extending across the midline, with a few of the coils reaching into the lesser pelvis. From the lower part of the left side of the abdomen the coils extend across the vertebræ to the right of the umbilicus. They then extend into the right iliac fossa and from there into the lesser pelvis, from which the last coil of the ileum extends upward to terminate at the ileocecal junction (Fig. 148).

Mills described the large intestine of hypersthenic individuals as being short and high in position (Fig. 149). The cecum is out of the iliac basin; the transverse colon is truly transverse and above the umbilicus; the descending colon is longer and straighter than in other types. In asthenic individuals the colon is low and longer than in other forms. The cecum is located in the small pelvis and is quite capacious. The transverse colon descends into the pelvis. The hepatic flexure is often not higher than the highest point of the right iliac crest nor is the splenic flexure always as high as the spleen. The latter flexure is, however, usually the most constantly located portion of the large intestine.

Moody, Chamberlain, and Van Nuys made a study of the position of the large intestine in 300 healthy males and a similar number of females. With the subjects in the anatomical position, they say that the cecum is in the cavity of the true pelvis in 60 per cent of males and 63 per cent of females, and that the transverse colon varies much in shape and position. They found that the transverse colon may either be a shallow loop, U- or V-shaped, with equal or unequal limbs, with the apex either to the right or left, or in any intermediate position. Often the right or left portions lie over the ascending or descending colon so that their images are superimposed on Roentgen-ray films. They found that in males, in the erect posture, the most dependent portion of the transverse colon varies from a position 1 centimeter (0.4 inch) above the interiliac line to a position 17.5 centimeters (7 inches) below the line; and in females from the same level above to 18.5 centimeters (7.4 inches) below the line.

ROENTGENOLOGIC EXAMINATION.

Roentgenologic examination is one of the few and by far the most useful of the direct methods of examining the gastrointestinal tract for evidences of disease. Since it is a method of visual study, either of images on the fluorescent screen or on films, it follows that most conditions which can be detected by it are macroscopic and of an organic nature. Those functional disturbances which produce

abnormalities in the movements, either of the viscera themselves or of the contents through the stomach and intestine, or which, by spasm or otherwise, produce variations in outline or shape, also often can be detected. Holmes and Ruggles say that the diagnoses of the average roentgenologist are correct in about 80 per cent of cases, and that a skillful roentgenologist, working under most favorable circumstances, is correct in from 90 to 95 per cent, a statement that shows the importance of Roentgen-ray examination of the gastrointestinal tract as a diagnostic method.

All examinations for the purpose of seeking pathological changes in the gastrointestinal tract, of which the gall bladder and liver may be considered a part, should follow a certain established routine. Only in this way will the different parts be given consideration and sufficient evidence collected to make a diagnosis of the patient's ailments. When the patient's symptoms are at all vague, not pointing directly to some particular condition, most roentgenologists will agree that the examination should include the entire tract; conclusions from incomplete are more apt to be incorrect than those from complete examinations. In time and materials required, in meticulous attention to details, in the painstaking collection of abnormal findings, and in the final correlation of clinical and Roentgen-ray evidences of disease, the roentgenologic examination of the gastrointestinal tract presents more difficulties than most others the roentgenologist is called upon to make.

Any plan for a routine examination of the gastrointestinal tract may be adopted, the one selected being followed to the exclusion of others. The gall bladder should be the first organ examined. When this has been completed, the study of the alimentary canal may be begun or the two examinations may be carried on simultaneously. The stomach and intestinal tract may be examined by either the single or double-meal method. When using a double meal, the patient is given or takes the first meal as breakfast at a certain time in the morning. Six hours later, not having eaten in the meantime, he presents himself at the Roentgen-ray laboratory. The emptying of the stomach, the passage of the meal through the intestinal tract during the first six hours, and the condition of the structures in the right iliac fossa can be determined by the examination of the first meal. The second meal is then ingested in the laboratory for the purpose of examining the esophagus, stomach, and duodenum.

If the single-meal method is used, the patient comes to the laboratory in the forenoon without having eaten breakfast. He is given

the first meal and the upper part of the alimentary canal is examined. When this is finished he leaves, but returns six hours later, still fasting, for the sixth-hour examination. The double and single meal methods should give identical results; the former has the advantage of requiring but one visit to the laboratory and one examination. In large clinics where numbers of patients are seen or in larger cities where patients must travel for some distance, the double-meal method is usually used. In smaller communities or in a hospital practice, the single-meal method may be followed.

The next examination should be made after an interval of approximately twenty-four hours to determine the rate of passage of the meal through the large intestine and to look for abnormalities. The patient should be instructed not to take laxatives or enemas between the first and twenty-fourth-hour observations. If the time of complete emptying of the colon is to be determined, studies after twenty-four hours should be made to suit the individual case. The examination is completed by administering a barium enema so that the colon is completely filled. If a careful search is to be made for filling defects and other organic changes, the colon must be emptied of the ingested barium. This can be done by having the patient take a mild laxative the night preceding the examination, to be followed on the morning of the next day by a cleansing enema of soapsuds or lukewarm water. If the colon examination is to be made for redundancies and the condition of the musculature, etc., the barium enema may be given following the twenty-fourth-hour meal examination. The barium in the intestinal contents will usually be more concentrated than that in the enema so that the filling by the two portions can be distinguished. This does not, however, detract from the results.

While a routine procedure should be followed in all gastrointestinal examinations so that results will be comparable, it is inadvisable to follow too much the same steps for every patient. To obtain the best results a certain amount of individualization is necessary.

In the following sections each part of the examination is considered as a unit. It must be remembered, however, that each is only a part of a complete examination.

THE GALL BLADDER.

The gall bladder is frequently the seat of infection and quite often contains stones. Either condition may produce direct or reflex

symptoms in the upper part of the abdomen. Since such symptoms are so often reflex and of a vague and indefinite nature, any method of examination that materially assists in detecting the presence of gall-bladder disease is of considerable value. Of these, Roentgen-ray examination is undoubtedly the most reliable.

Roentgen-ray examination of the gall bladder has passed through distinct phases, preceding and following the development of cholecystography, excellent accounts of which are given by Graham, Cole, Copher and Moore, and by McCoy. While it is true that gall-bladder examination was attempted by some of the masters of the art working in the larger laboratories at an earlier period, it was not until after the development of double-coated films and intensifying screens of good quality, and probably not until after the publication of the excellent monograph by George and Leonard in 1922, that this method was widely used. At first attempts were made to show a large percentage of gallstones and as many pathological gall bladders as possible on Roentgen-ray films, and a careful study was made of the rest of the alimentary canal, especially the stomach, duodenum, and colon, for adhesions, pressure defects, etc., which were considered as important secondary evidences of gall-bladder disease.

In this phase the greatest importance was placed on roentgenograms of the very best quality. Extreme contrast and a great amount of detail are required to show gallstones, especially those with but little calcium content, and to picture pathological gall bladders. In an examination several films were usually taken, with slightly varied exposure factors, in an attempt to find the combination that gave the best film. The advances made during this phase in roentgenography of the gall bladder are just as important today; for, if the gall bladder does not fill by cholecystography, films of the finest quality will be more likely than others to show gallstones, thus increasing the percentage of correct findings.

The last phase in the Roentgen-ray examination of the gall bladder began in 1924 following the origination of cholecystography by Graham and Cole. These investigators made use of the facts that one of the chief functions of the gall bladder is the concentration of the bile as it is received from the liver and that certain dye preparations of the phthalein series are excreted from the blood by the liver as constituents of the bile. By using dye preparations containing bromine and iodine they found that these substances, when concentrated in the gall bladder, rendered the bile sufficiently dense to Roentgen-rays that a distinct shadow of the normal gall bladder

could be obtained on roentgenograms. Cholecystography is then really a test of gall-bladder function, the organ being considered normal when a good concentration of bile is obtained and when there are no stones present. Experience has shown that gall bladders that do not concentrate normally are diseased. Thus the test becomes of clinical value.

The first preparation used for this purpose was sodium tetrabromphenolphthalein. This was soon replaced by sodium tetraiodophenolphthalein as being less toxic and requiring a smaller quantity. To these has been added sodium phenoltetraiodophthalein which both fills the gall bladder and makes it possible with one injection to do a functional test of the liver as well as a Roentgen-ray examination of the gall bladder. Both the intravenous and oral methods of administering the tetraiodo and tetrabrom salts have been used. There are objections to both these methods. The intravenous administration requires extra apparatus, careful attention to numerous details of sterilization, etc., and has been known to be followed by serious reactions. It is probably not now used in more than a few places except in large institutions where there is an abundance of technical assistance. Although diagnoses made by the intravenous administration are somewhat more reliable, in the usual roentgenologic practice its disadvantages probably outweigh its advantages.

When given by mouth the hydrochloric acid of the gastric juice may change some or all of the sodium tetraiodophenolphthalein to an acid and render it insoluble. Although this takes place, it is quite certain that in a majority of normal persons either some of the dye passes through the stomach unchanged or the alkaline intestinal juices change enough of it back to the soluble form to fill the gall bladder and make it visible on Roentgen-ray films. If given in plain gelatin capsules in doses of 0.5 gram for each 20 pounds of body weight with the evening meal and the patient instructed to lie on the right side to hasten the exit of the capsules from the stomach, a rather large percentage of normal gall bladders will be visualized the following morning.

To prevent the effect of the acid of the gastric juice, the dye has been given in gelatin capsules hardened in formalin, coated with keratin, stearic acid, and salol, and administered either with or without alkalis. When given in these ways, too often the capsules fail to disintegrate. Also, the oral administration is often followed by nausea and vomiting, even before the capsules all leave the stomach, and by a diarrhea.

More recent and apparently more efficient methods of oral administration of tetraiodophenolphthalein have been advocated by Levyn and Aaron, and by Fantus. Levyn and Aaron recommend that 3 grams of the dye be dissolved in an ounce of distilled water and the solution filtered. This is added to a glass of Welch's grape juice, the mixture well stirred, and drunk. The originators of this method say that the weak organic acids in the grape juice change the preparation from a sodium salt to an acid which precipitates out as a fine insoluble precipitate. In this form it passes through the stomach without being affected by the acid of the gastric juice. In the intestine the acid is changed back to a soluble salt, which is absorbed.

Fantus recommends that the dye be precipitated from a solution by the addition of carbonated water or by passing a stream of carbon dioxide through it. This colloid precipitate may be stabilized by the use of very dilute tragacanth mucilage. In this form the preparation may be taken mixed with water. Given in this way, 2 grams of the dye are said to be enough, nausea and vomiting are largely prevented, and the dye is well absorbed.

Although nausea, vomiting, etc., may be quite annoying when giving these preparations by the oral method, the greatest objection is the irregularity in the absorption of the drug from the intestinal tract. Since it is impossible to determine the amount that has been absorbed, if a gall-bladder shadow is not visible on the films and the fecal material in the hepatic flexure of the colon is rendered faintly visible by the dye it contains, one would suspect that the failure of visualization of the gall bladder might be due to failure of the dye to reach the circulation. When this condition exists, before subjecting the patient to an operation without other evidence of pathology in the gall bladder than the failure of visualization, the test should either be repeated by the oral method or the dye given intravenously. When repeated orally, the second dose of the dye, plus absorption of what remains of the first, will render visible a very large proportion of normal gall bladders, the results approaching in accuracy of diagnosis those obtained by the intravenous method.

Cholecystography may be performed by giving the dye by either the intravenous or oral method. If one wishes to administer it intravenously, it would probably be better to learn the technique first hand by visiting some hospital or clinic where the method is extensively used. Graham, Cole, Copher, and Moore have repeatedly published the details of the methods used by them.

In the recent monograph by Graham, Cole, Copher, and Moore the technique given, somewhat abbreviated but in almost a direct quotation, is as follows:

Two and five-tenths grams of phenoltetraiodophthalein are dissolved in 30 cubic centimeters or more of freshly distilled water, with the aid of gentle heating, and the solution filtered through filter paper. If tetraiodophenolphthalein is used, the dose is 3 to 3.5 grams dissolved in 40 cubic centimeters or more of freshly distilled water. Either solution is sterilized by boiling in a water bath for fifteen to twenty minutes, and when cooled, is ready for injection. Solutions prepared in this way may be kept for from two to three weeks by sealing in individual doses in glass ampoules. If a precipitate forms in the ampoules, the solution should be carefully withdrawn with a syringe or refiltered. The injection is made with a syringe and needle, in the morning, between 8 and 9 o'clock, with the stomach empty and with the patient lying down. The phenoltetrachlorphthalein is given in one dose; the tetraiodophenolphthalein in divided doses one-half hour apart. Care should be taken to establish a free flow of blood from the vein before injecting the dye. The injection should be followed by the introduction of physiological salt solution to wash out the vein, thereby reducing the possibility of venous thrombosis. The importance of using absolutely clean glassware and freshly distilled water of known purity in preparing and injecting the solutions is strongly emphasized.

Breakfast is omitted on the morning of the injection and lunch limited to a carbohydrate liquid intake. The stomach contents may be alkalinized by the administration of frequent doses of sodium bicarbonate by mouth. As given in preceding articles, roentgenograms are taken in series at four, eight, twenty-four, and thirty-two hours after the injection.

Sodium tetraiodophenolphthalein is the only preparation now extensively given by the oral method. The dosages and methods of preparation have varied rather widely. Oakman recommended 5 grains for each 20 pounds of body weight in salol-coated capsules; Whitaker, Millikin, and Vogt, 5 grains for each 10 to 12 pounds in stearic-acid coated pills; Manees and Robinson, 15 grains for each 25 pounds in formaldehyde-hardened capsules; Stewart and Ryan, in 3.5-gram doses in keratin-coated capsules; Stewart and Illick, in 3.5-gram doses in plain gelatin capsules; Levyn and Aaron, 3 grams precipitated from a solution in grape juice; Fantus, 2 grams in an

emulsion, and Graham, Cole, Copher, and Moore give 4 to 5 grams in 5 to 6 capsules, using plain or salol-coated capsules, each capsule containing 0.8 gram of the dye, 0.1 gram powdered agar, and 0.1 gram sodium bicarbonate. To neutralize the hydrochloric acid of the gastric juice, sodium bicarbonate is often given before, during, or after the ingestion of the capsules. Also various instructions with reference to the kind, amount, and time of ingestion of food are included.

Stewart and Illick have devised a method of oral administration based on the physiological experiments of Boyden which they advocate as a standardized method of oral cholecystography. These authors say that "Any variation from the normal physiologic activity, even though slight, warrants suspicion that the functional efficiency is impaired and a probability, therefore, of a pathological lesion." The procedure devised by them would seem to be one of the most sensible yet advocated, its only bad feature being the time required to complete the study. Physiologically the gall bladder completely empties in from one to two hours after a fat meal, it then slowly fills for eight to ten hours, becoming fully distended at twelve hours. With continued starvation the bile is concentrated, reaching its maximum in four to five hours more. Based on these observations, the method advised by Stewart and Illick is as follows:

The gastrointestinal tract is cleansed by a mild cathartic the night before the first examination. The patient reports in the afternoon of the first day for a preliminary examination of the gall bladder for the purpose of detecting radiopaque gall stones. He is then given eight gelatin capsules containing 3.5 grams of tetraiodophenolphthalein—the contents of one sealed ampoule, the capsules being filled just before they are given the patient—and four capsules each containing 10 grains of sodium bicarbonate. The directions accompanying the capsules instruct the patient to eat a meal at 6 P.M. consisting of soup, creamed chicken or soft-boiled eggs, vegetables, bread and butter, and a glass of milk. The capsules are taken, beginning at 9:30 P.M., two of these containing the dye and one containing the alkali each fifteen minutes with half a glass of water until all are taken. The patient reports, still fasting, at 9:30 the following morning for the twelfth-hour examination. The fasting continues, the sixteenth-hour examination being made four hours later. Lunch is then allowed consisting of 2 soft-boiled eggs, 2 pieces of well-buttered toast, and a cup of tea, the eighteenth-hour examination being made one hour later. The evening meal is allowed but

the patient returns the following morning for the thirty-sixth hour examination. The barium meal is then given and the gastrointestinal tract examined in the usual way.

This method of oral cholecystography presents certain advantages, the chief of which are that it is based on the physiological activity of the normal gall bladder and that the dye preparation given is known to be fresh. The authors insist on the use of pure fresh drug and point out that the unsatisfactory results from the oral method are probably due to the use of dye that has been exposed or allowed to deteriorate in the various commercialized preparations that have been used. The only objection, and it is a serious one, to this method of cholecystography is the time required. Two full days are necessary for the examination of the gall bladder, two or three additional days for the barium meal and enema examination of the gastrointestinal tract, requiring four to five days for the complete examination. When one deals with a class of patients that object to an examination requiring two days and refuse to stay longer, this objection is a valid one.

To overcome this objection, Watkins and Mills combine the cholecystographic and the barium-meal examinations in an ingenious manner. The dye is given at night, the films of the gall bladder being made the next morning. Irrespective of the findings, the barium meal is given at once and the stomach and duodenum examined. The opaque meal is presumably of such a nature, not containing fat, that the usual functioning of the gall bladder is not interfered with. Six hours later, the patient fasting in the meantime, the gall bladder is again examined for concentration of the bile. At the same time the progress of the meal in the intestinal tract is observed. The fat meal then may be ingested and the examination made for the contraction and emptying of the gall bladder at the end of an hour. The usual meals are allowed and a thirty-sixth-hour film taken the following morning. This method may be objected to on the grounds that the meal may interfere with the function of the gall bladder and that barium in the stomach, duodenum, or colon may interfere with the proper delineation of the gall bladder at the second and third observations. It has the advantages, however, of making possible the advisable multiple examinations of the gall bladder and not requiring more than two or three days to complete the study of the gall bladder and gastrointestinal tract.

Irrespective of the type of preparation used, patients to be

examined by the oral method of cholecystography must be given the dye in the evening and the first films exposed the following morning. If the examination is to begin before 9 A.M., the dye should be given during the evening meal or just afterward; if the examination is to begin at 9 o'clock or later, the dye may be given as late as 9 or 9:30 o'clock at night. The question of fat in the evening meal is an unsettled one. While many examiners give specific instructions for a meal without fat, as given above, Stewart and Illick recommend its use. Based on the findings of Boyden, their position is probably well taken. If not ingested at night, a fat meal at noon before the administration of the dye at night should be advantageous.

If either coated or uncoated capsules are used, it seems best to divide the dose into three or four parts and have the patient take them fifteen minutes apart. Drinking a glass of water after each dose, lying on the right side, and taking doses of sodium bicarbonate would tend to hasten the exit of the capsules from the stomach and neutralize the acidity of the gastric juice. If given in solution by the methods suggested by Levyn and Aaron, or by Fantus, the solution may be taken so as to have an interval of twelve to fourteen hours before the first examination the following morning. After the dye has been taken, the patient should not have food nor anything to drink but water. Medicines of all kinds, especially laxatives, should be prohibited. Since that which is expected tends to occur, and although doing so might save many telephone calls during the night, it is probably best not to tell patients that the drug may cause nausea and vomiting.

After the intravenous administration the gall bladder is well filled in about four hours; after the oral administration in twelve to fourteen hours. The first Roentgen-ray examination should be made at these intervals. If the patient fasts for four hours longer, the normal gall bladder will be slightly smaller and the dye more concentrated. For this reason many examiners make a second examination after such an interval. If a test of the emptying power of the gall bladder is considered necessary, after either the first or second examination the patient is instructed to eat a meal rich in fat, and additional films are exposed one to two hours later. A meal containing two eggs and a glass of cream, served in any way the patient desires, is admirable for this purpose. Although Moore and his associates think that this is not necessary, such an examination is routine in many places. If, during oral cholecystography, a shadow is obtained that might be less dense than what would be

considered normal concentration, the presence or absence of contraction after a fat meal would be a valuable additional evidence of the presence or absence of infection. It has been stated also that non-opaque gallstones not apparent on films of the fully-distended gall bladder may become visible on those of the partially empty viscus.

We have examined several hundred patients by means of cholecystography. A short and stormy experience with the intravenous method prompted its complete abandonment in favor of oral administration. Keratin, stearic acid, salol, and various commercially coated capsules have been tried; the dye has been given in gelatin capsules without coating, in solution according to the method suggested by Levyn and Aaron, and in at least three of the commercial liquid preparations. Of these methods of administration the most satisfactory results have been obtained when using freshly filled gelatin capsules or similar capsules coated with keratin or the freshly precipitated acid in grape juice as suggested by Levyn and Aaron. We incline to the opinion of Stewart that better results will be obtained from capsules filled in our own laboratory or from a freshly prepared solution than from any commercial preparation. Should one prefer the use of capsules the directions given by Stewart and Illick for their preparation and administration are probably the best. At present we are using the freshly precipitated acid in grape juice with satisfaction. It is only fair to say, however, that this method may be replaced at any time by any one that offers hope of more reliable results or fewer reactions.

Our method of procedure is as follows: On the day preceding the examination the patient is given a prescription for a freshly prepared, filtered solution containing 3 grams of tetraiodophenolphthalein in 30 cubic centimeters of distilled water. The patient is sent to a pharmacist with whom arrangements have been made for supplying this preparation from a 100-gram bottle of dye that is kept under conditions that prevent deterioration. Typewritten directions which are given with the prescription are as follows:

"Eat a light supper, not later than seven o'clock, consisting of soup, creamed chicken or 2 soft-boiled eggs, vegetables, toast and butter, and a glass of whole milk. One hour after supper pour the bottle of blue medicine into a water glass and add enough Welch's grape juice to fill the glass. Stir it for one full minute and drink it all. Neither food nor medicines of any kind may be taken after

this. Water may be had as desired. Come to this office, without breakfast, tomorrow morning at ——— o'clock for the *X*-ray examination."

At the Roentgen-ray examination the following morning two films are exposed and developed immediately. These are examined and if unsatisfactory additional films are taken until satisfactory ones are obtained. The barium meal is then given and the examination of the gastrointestinal tract begun. The procedure suggested by Watkins and Mills of making additional films of the gall bladder at the sixth-hour examination of the meal in the intestinal tract, then giving a fat meal and making a third examination one hour later is usually followed. Occasionally, when the Roentgen-ray findings suggesting a pathological gall bladder are present without definite clinical signs, a second dose of dye is given at a later date for a check on the first. This method of examination has been very satisfactory, giving a high percentage of correct results.

Irrespective of the method of giving, the time of the examination, or whether the dye is used or not, the Roentgen-ray examination is the same. Since the gall bladder is located in the anterior part of the abdominal cavity near the posterior surface of the anterior abdominal wall, the prone position brings the organ nearer the cassette than any other. Hence it should be used, with only slight modifications, for all Roentgen-ray examinations. The patient should be placed on the table in this position, with the head turned to the right so that the chin is over the right shoulder. The left upper extremity should be along the side of the trunk; the right may be flexed around the head (Fig. 141). In all examinations the rays from the tube should be directed perpendicularly to the table top. If any variation from a direct postero-anterior path of the rays is necessary, it should be obtained by slightly turning the patient and not by tilting the tube.

In order that the tube may be properly focused and the cassette correctly placed, with the patient prone, the approximate position of the gall bladder with reference to the dorsal surface of the abdomen must be determined. The landmarks by which this must be done are the lower ribs, the spinous processes of the vertebræ, and the posterior part of the crest of the ilium. Usually the eleventh and twelfth ribs can be palpated as they extend downward and lateralward from their vertebral attachments. The location of the gall bladder with reference to the ribs varies with the habitus of the

patient and the amount of abdominal fat. With a patient of average habitus, approximately intermediate between the hypersthenic and asthenic, on a direct postero-anterior view the gall bladder will appear either superimposed by, or lying just below, the shadow of the twelfth rib. For this habitus, therefore, the central rays from the tube should be centered over the twelfth rib midway between the vertebral column and the lateral margin of the body and the cassette placed so that this point is over its middle. When so placed, it will be found that the tip of the twelfth rib lies near the junction of the upper three-fourths with the lower fourth of the lateral margin of the cassette (Fig. 141).

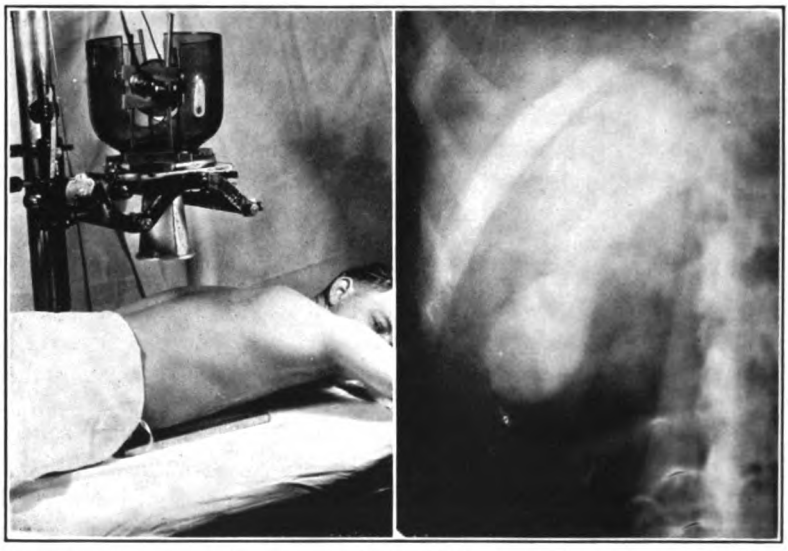

FIG. 141.—Postero-anterior exposure of the gall bladder, patient of average habitus.

For the examination of many patients this position will be correct. For those who approach the hypersthenic habitus, or who have a large amount of abdominal fat, the position of the gall bladder will be higher; for those who approach the asthenic habitus, or who have lax abdominal walls, the position will be lower. Occasionally with a patient who is both hypersthenic and corpulent the gall-bladder shadow will lie high under the ribs, even as high as to be superimposed over the shadow of the ninth intercostal space (Fig. 142). For such patients the tube should be centered over the eleventh rib or tenth intercostal space and the cassette placed accordingly.

In patients who approach the asthenic habitus, the gall bladder is not only lower in position, but it approaches the midline of the body. For such the tube should be centered over the interval between the twelfth rib and the highest part of the iliac crest and closer to the vertebral column. In examining such patients it often is advisable to place a small triangular sand bag (one with an angle of 20 to 30 degrees) under the right hip bone, thus elevating it from

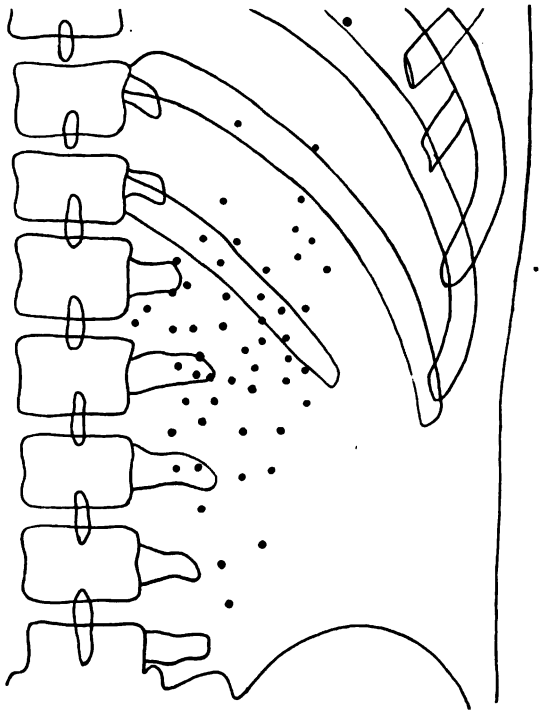

FIG. 142.—The position of the gall bladder as shown on films of 54 unselected patients. The dot represents as nearly as possible the center of the fundus. Most of them are located behind the shadow of the twelfth rib or in the angle formed by the rib and the lateral margin of the vertebral column.

the table. This will turn the body enough to throw the shadow of the gall bladder clear of that of the spine. In rather rare instances the shadow of the gall bladder may reach over that of the iliac crest into the right iliac fossa.

The best practice in gall-bladder roentgenography is that recommended by George and Leonard of exposing one or two films and waiting until these have been developed and examined before

proceeding. In this way the position of the tube, the cassette, and even the patient, may be changed, and the exposure factors varied until the best possible films have been produced. Films made with a low voltage, high milliamperage, and a short exposure time—those with the maximum contrast and detail—are best for this purpose. They should show the eleventh and twelfth ribs, the vertebral column, especially the transverse processes, the edge of the psoas muscle, the lower border of the liver, and the outline of the right kidney with considerable distinctness. The suspension of respiration should be as nearly perfect as possible. On the films there usually is shown a small amount of gas in the colon. If the margins of the black shadows of this gas are distinct, the respiratory stoppage is satisfactory; if they are blurred, the films are not satisfactory.

The question arises as to whether a Potter-Bucky diaphragm should be used. This is largely a matter of personal choice. It would seem, however, that with thin and moderately thick patients, 18 centimeters in thickness or under, the increase in exposure and the distortion caused by separating the patient and film more than offset the advantages of the diaphragm. For thick persons, however, the use of the diaphragm is a distinct advantage. With the diaphragm a cone is unnecessary and a large film may be used. The 10- by 12-inch size is the most practicable. If the diaphragm is not used, a small cone is advisable. One that is $2\frac{1}{2}$ inches at the smaller end and $3\frac{1}{2}$ to 4 inches at the larger end is the proper size, giving an exposed area on a film about 8 inches in diameter at a 25-inch distance. When using a cone of this size, $6\frac{1}{2}$- by $8\frac{1}{2}$- or 8- by 10-inch films are large enough for this work.

THE LIVER.

Hepatic enlargement is the principal condition for which the liver may be examined by Roentgen-rays. A large film of the upper part of the abdomen will show the upper surface of the liver clearly outlined against the air-filled lung, separated only by the diaphragm. On such films, especially when made with a Potter-Bucky diaphragm. the right border and most of the inferior margin of the right lobe can be identified. Pfahler has made use of this fact and has described a method of determining the size of the liver. He has also collected figures on a large enough series to establish the normal limits of liver dimensions.

The technique described by Pfahler is as follows:

"For these measurements the subject is placed in the supine position upon a Potter-Bucky diaphragm. A 14- by 17-inch film in a double screen cassette is placed crosswise so that the lower border will include about 1 inch of the upper border of the crest of the ilium. This will, in practically all instances, include the entire liver, both kidneys, and the spleen.

"The tube is centered over the ensiform, at a target-film distance of 25 inches. It must be admitted that at this distance there will be some inaccuracy due to exaggeration according to the thickness of the patient, but one is surprised at the slight difference that this makes in the figures. A slight allowance will have to be made, therefore, in a very thick patient."

On a film made in this way two measurements are made. One is the "length" of the liver, made from the highest point to the lowest border of the tip of the right lobe. The other is the "thickness," measured from the upper to the lower border in an oblique direction—"In a direction that would be considered the thickness if one were to lay the lower border on a horizontal plane."

Pfahler found that neither the sex, age, height, nor weight had much influence on the size of the liver. He gives the average normal length of the liver shadow as 21.3 centimeters, with normal variations from 18 to 22 centimeters, the longest being found in those that were the tallest and of the greatest weight. The average thickness is given as 12.8 centimeters, with normal limits of approximately 10 to 14 centimeters, the greatest thickness being found in those persons of the greatest body weight and hence the greatest body thickness. He says that when these limits are exceeded an explanation should be found.

THE ESOPHAGUS.

Organic diseases of the esophagus are rather uncommon. Those occasionally seen, listed in the order of probable frequency, are carcinoma, cicatricial strictures, cardiospasm, and diverticuli. Roentgenologic examination is most important in the detection of any of these conditions.

Routine fluoroscopic observation of the act of swallowing should be a part of the examination of each patient to whom a barium meal is given. Not only will it detect those rare cases of diverticuli, but displacements of the esophagus caused by mediastinal or thoracic

lesions may be a valuable diagnostic finding. In making this examination the patient stands behind the vertical fluoroscope in the right anterior oblique position with the chin turned over the left shoulder and the cup containing the barium mixture in the left hand. Current is sent through the tube and the patient slowly rotated back and forth until the clear space seen between the spine behind and the heart and aorta in front is at its widest. When this has been found, the patient is instructed to drink a swallow, and the barium mixture is observed as it passes through this clear space into the stomach.

The usual liquid barium meal will pass rapidly down the esophagus. If the routine inspection of the esophagus leads to the suspicion of organic trouble, or if there is difficulty with swallowing or other symptoms that indicate esophageal involvement, a special examination should be made. For this a much thicker preparation than the usual meal should be used. Hirsch recommends a bismuth-acacia mixture, 1 part of mucilage of acacia to 4 parts of bismuth; barium may be substituted for the bismuth. This makes a thick, sticky mass which is fed to the patient a teaspoonful at a time. It passes slowly down the esophagus clinging to its walls, so that organic defects become apparent. A thick mixture of barium sulphate with any suspending medium will serve about as well.

Roentgenograms of the esophagus should be made in the right anterior oblique position with the patient either erect or prone. The amount of rotation of the patient should be the same as that at which the esophagus was best seen with the fluoroscope. If the patient is cautioned to remain immobile after the fluoroscopy has been completed, the room lights may be turned on and the position of the patient carefully noted. It is then rather easy to duplicate this position with the patient before the vertical cassette-holding device, the film occupying the same relative position as the fluoroscopic screen. Unless there is almost complete obstruction so that the barium mixture does not pass rapidly through the esophagus, better films can be secured with the patient in the right anterior oblique position on the table. Manges points out the value of this position. The patient's right arm is placed along the trunk, the chin turned over the left shoulder, the left knee is flexed, the left elbow is flexed and supports the patient, and the vertebral column is straight (Fig. 143). The correct degree of turning may be determined by horizontal fluoroscopy. An assistant holds a cup of the barium mixture in which is a short, wide drinking tube. The

patient takes two or three large swallows and then is told to stop and remain immobile while the exposure is made. Antero-posterior films are satisfactory for the cervical part of the esophagus or for that part which passes through and is located below the diaphragm.

In centering the tube for roentgenograms of the esophagus it must be remembered that its average length is only 9 inches, that it begins above at the cricoid cartilage anterior to the sixth cervical vertebra, and that it terminates on the left of the tenth thoracic vertebra which is just below and on the left of the sternoxiphoid

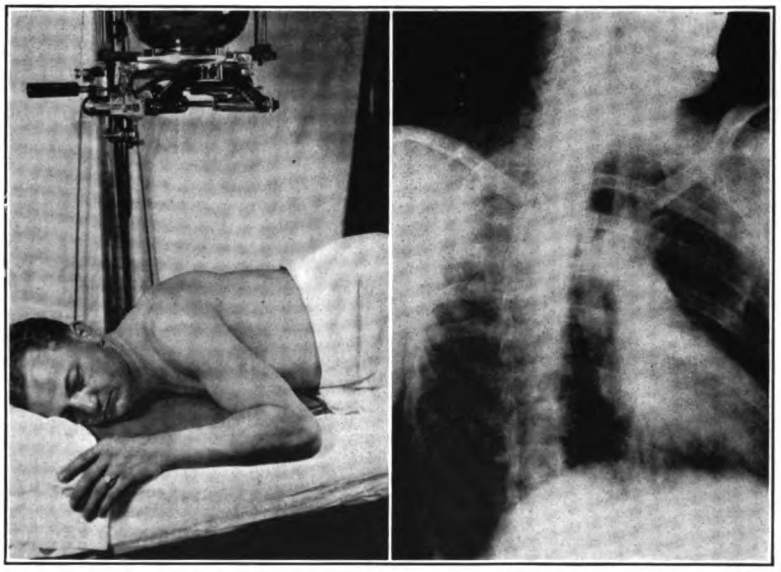

FIG. 143.—Right anterior oblique prone exposure of the esophagus. The esophagus is located in the space between the mediastinum and the vertebral column.

junction. Its mid-point would be about level with the angle of the sternum in front and the cartilage between the fourth and fifth thoracic vertebræ behind. For antero-posterior views of the upper and lower ends the tube should be centered just above the jugular notch and over the sternoxiphoid junction. For the right anterior oblique view of the entire esophagus the tube should be centered at about the interval between the fourth and fifth thoracic vertebræ. For views of the entire esophagus the 11- by 14-inch film is adequate; for views of either the superior or inferior extent smaller films may be used.

THE STOMACH AND DUODENUM.

Roentgenologic examination of the stomach and duodenum are of the greatest importance in detecting the presence of organic lesions and for determining changes from normal in the size, shape, position, peristaltic activity, tonus, motility, and mobility of these viscera. Since they are not themselves opaque to Roentgen-rays, the examination must be done by the use of some sort of material in the form of a meal that is opaque to Roentgen-rays, thus creating an artificial density of their contents. Barium sulphate, suspended in some material that is palatable, is the opaque substance now universally used. The suspending medium may be any liquid substance that is viscid enough to hold the barium in suspension. In addition, Carman says that it should not be too thick to fill small recesses, should not unduly stimulate gastric secretion, neither accelerate nor retard motility, and it should be at a temperature of about 70° F. Arens and Bloom, however, see no advantage in a warm mixture, preferring a cold one as being more palatable. The material most commonly used is buttermilk or fermented milk. Malted milk, various preparations of corn or potato starch, cooked cereals, and mixtures of gum acacia and water also are used. The proportions are 4 ounces (120 grams) of barium sulphate in from 12 to 16 ounces of the suspending medium.

Since soluble barium salts are poisonous and have caused the death of a few persons, special precautions should be exercised in selecting the preparation used. It is wise to use only barium sulphate prepared for Roentgen-ray diagnosis by a reliable manufacturer and delivered in original packages. It may be going a little too far to say that it should only be bought from dealers in Roentgen-ray supplies, yet, on two occasions in our experience, druggists have sent the poisonous sulphite when the sulphate was ordered. If the patient is to take it at home, as is done with the double-meal method of examination, it is better to dispense the barium from the laboratory and not have the patient get it at a drug store on a prescription.

Roentgenologic examination of the stomach and duodenum should be both fluoroscopic and roentgenographic. The barium meal should be ingested with the patient behind the fluoroscopic screen so that its passage down the esophagus and the filling of the stomach may be observed. The pylorus of the empty stomach is usually relaxed, thus making it possible rapidly to force the first few swallows of the meal into the duodenal bulb, filling it completely, so that it

may be hastily examined for deformities. When the meal has all been taken the entire stomach and the duodenal bulb should be carefully examined for abnormalities in size, shape, position, correspondence with the patient's habitus, tonus, peristalsis, mobility, and especially for filling defects. Filling defects of ulcer in the stomach are most often located on the lesser curvature near the pylorus. However, since this region is readily shown in profile on films, both surfaces of the stomach should be carefully inspected. In many instances, in the direct postero-anterior projection on the screen, some part of the stomach or duodenum is obscured by other portions, making it necessary to turn the patient so that all parts may be seen. Most commonly the duodenal bulb is located behind the prepyloric portion of the stomach, requiring rotation of the patient to the right anterior oblique position for an unobstructed view of it. Fluoroscopy in various horizontal positions often gives valuable information.

The number of films of the stomach that should be taken depends on the symptoms presented by the patient and on the findings of the preliminary fluoroscopy. While an expert may dispense with more than a film or two for purposes of a permanent record, it is unwise for those who are not thoroughly experienced to do so. In all cases at least one film of the entire stomach should be taken. If there is a history suggestive of ulcer or if there have been suggestive fluoroscopic findings, in addition to the large film of the entire stomach, there should be multiple exposures of the first and second parts of the duodenum, the pylorus, and much of the stomach, or of that part of the stomach where the suspicious findings were located.

Films of the stomach are usually made with the patient in the prone position. To prevent pressure of the spine across the stomach, the hips should be supported on a sand bag or a cushion and one or more pillows placed under the upper part of the thorax and head (Fig. 144).

In the change from the erect to the prone position there is considerable change in the form and position of the stomach. Moody, Chamberlain, and Van Nuys, who have studied this subject in healthy adults from the anatomical standpoint, say that: "These changes are due to several factors, chief of which are: (1) a movement cephalad of the whole stomach; (2) a movement of a large part of the contents of the stomach into its cardiac end; (3) a decrease in the long axis of the stomach with an increase in its transverse axis; (4) a movement cephalad and to the right of the pyloric end of

the stomach. This movement is sometimes so modified that the pylorus moves to the left instead of to the right. There are many combinations of these movements." These investigators found that, when prone, there was but little difference in the position of the most caudad part of the stomach in males and females; in all but approximately 13 per cent the entire stomach was above the interiliac line, and none was more than 2 inches below this line. They also found that the mid-point of the pylorus varied in position from approximately 8 centimeters to the right of the sagittal plane to 2 centimeters to the left, the most common location being in the zone between 2.5 and 5 centimeters (1 and 2 inches) to the right.

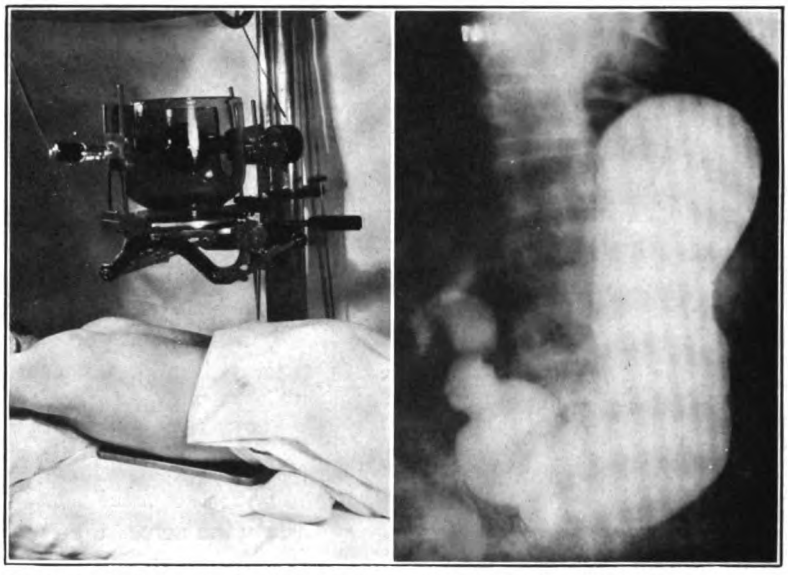

FIG. 144.—Postero-anterior prone exposure of the stomach. The hips are elevated on a sand bag and the upper part of the thorax on a pillow.

These anatomical observations, considered with the fact that it often is necessary to rotate the patient to show the duodenal bulb and pylorus in profile, indicate that posing a patient for films of the stomach is not always easy. However, certain general precautions may be stated. It is rarely necessary to have the lower margin of the film more than 1 or 2 inches below the line connecting the highest points of the iliac crests—the interiliac line—nor, when the patient is not rotated, the right margin more than 4 inches to the right of the sagittal plane of the body (Fig. 145).

If the same degree of rotation of the patient that showed the duodenal bulb unobscured by other parts of the stomach with the vertical fluoroscope is used in placing the patient in the right oblique position on the table for the exposure of films, experience has taught that the position usually will be correct.

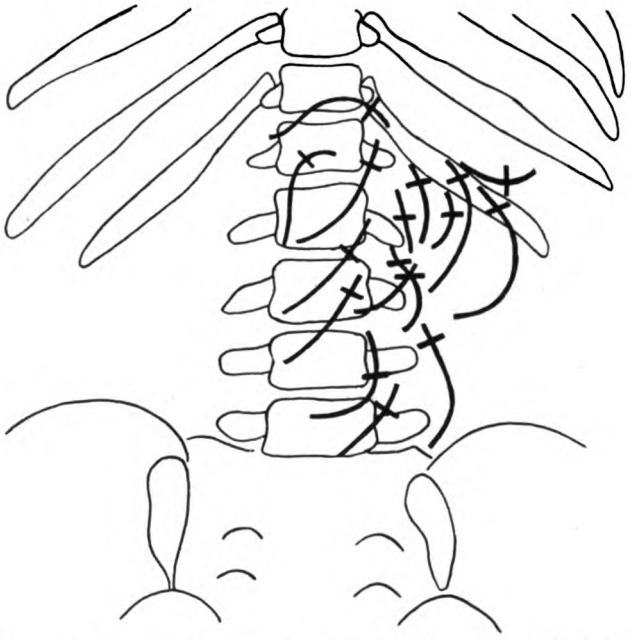

FIG. 145.—Showing variations in the position of the pylorus and duodenal bulb on films of the stomach made in the prone position. The longer lines represent the middle of the duodenal bulb and pyloric antrum; the cross lines represent the pyloric sphincter.

If the Roentgen-ray equipment includes a horizontal fluoroscope, the posing of the patient for films of the stomach can be done under fluoroscopic control and is a relatively simple procedure. If a horizontal fluoroscope is not available, the task becomes more difficult. Fasten with a plaster strip a small washer or coin over the umbilicus, then place the patient on the table in what is believed to be the proper position. Make a trial exposure on an 8- by 10-inch film, with the umbilicus near its lower middle part, and develop the film. By examining this the proper position for subsequent films with reference to the umbilicus can be determined.

Serial roentgenograms of parts of the stomach and duodenum are

made to show those permanent defects upon which are based the diagnosis of organic lesions. Since the stomach is constantly changing its shape and the duodenum fills and empties, on almost any single film there are irregularities in contour that may be suggestive of organic lesions. It is only when these are in the same position and of the same shape and size in a series of films or during

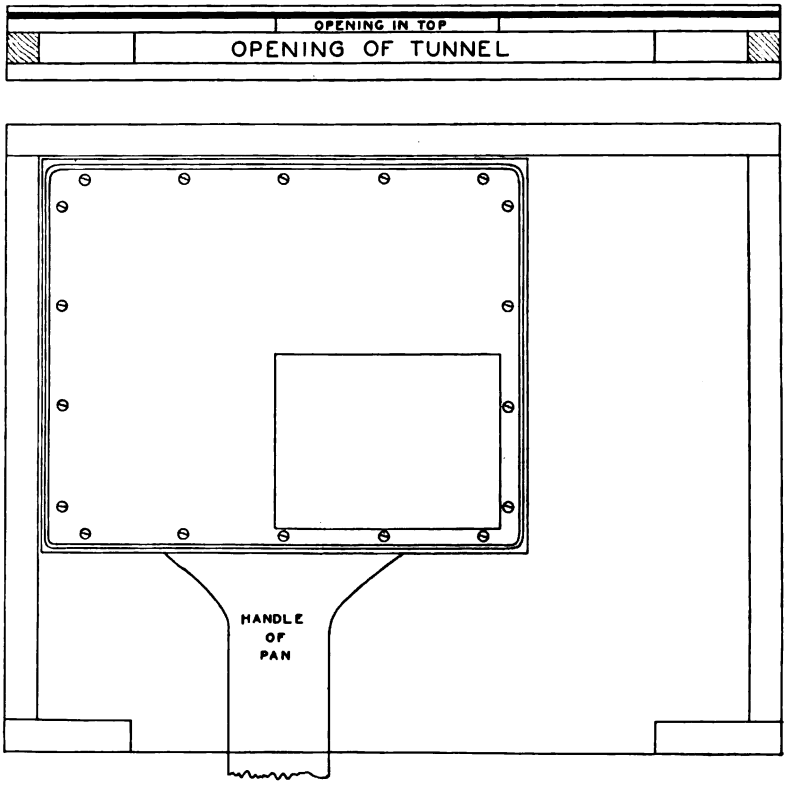

FIG. 146.—A cassette-shifting tunnel for multiple exposures of the stomach, using a 11- by 14-inch cassette.

a fluoroscopic examination that a diagnosis of a permanent defect with pathological significance can be made. To Cole belongs the credit for originating serial roentgenography of the stomach and duodenum. Such a series of films may be made by exposing a number of films one at a time, either with or without a device for changing them, such as a Cole plate-changing table, or by means of

a rather simple device multiple small exposures may be made on one large film.

Perhaps the simplest as well as one of the best of these is one that permits of making four exposures on one film, either of the 10- by 12-, 11- by 14-, or 14- by 17-inch size.[1] This consists of a tunnel large enough to accommodate the cassette and a pan by means of which the cassette may be moved in the tunnel (Fig. 146). In the top of the tunnel there is an opening which is the size of one-fourth of the film, the tunnel being of such dimensions that when the cassette in its pan is pushed into one corner the opposite fourth of the film

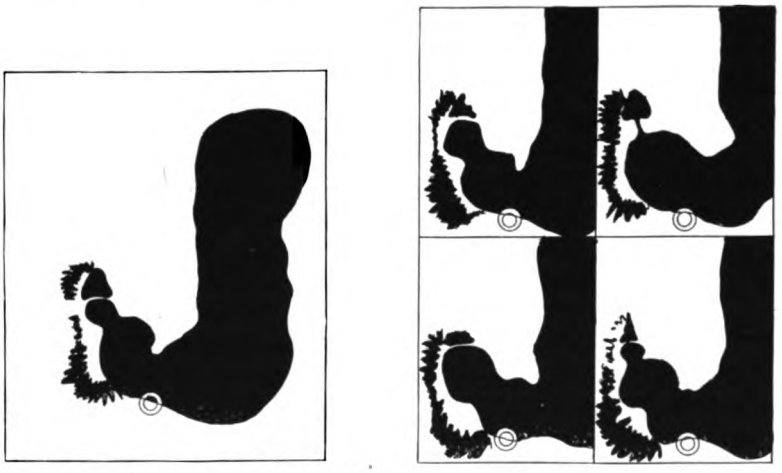

FIG. 147.—Multiple exposures of the stomach on a single film, using the device shown in Fig. 146. If a horizontal fluoroscope is not available, a metal washer may be fastened over the umbilicus, a large film exposed and developed, and the patient arranged over the opening in the cassette-shifting device with the umbilicus placed so that the desired portion of the stomach will be shown.

is under the opening in the center, the rest of it being covered by sheet lead in the top of the tunnel. This apparatus is placed on the Roentgen-ray table and the patient arranged over it. If available, the position of the patient with reference to the opening in the tunnel is controlled by horizontal fluoroscopy; if the equipment does not include a horizontal fluoroscope, the proper position of the patient may be regulated by making a trial exposure with an opaque disk on the patient's umbilicus, the position of the patient then being adjusted by placing the umbilicus over the appropriate part of the

[1] The author does not know who originally designed this apparatus.

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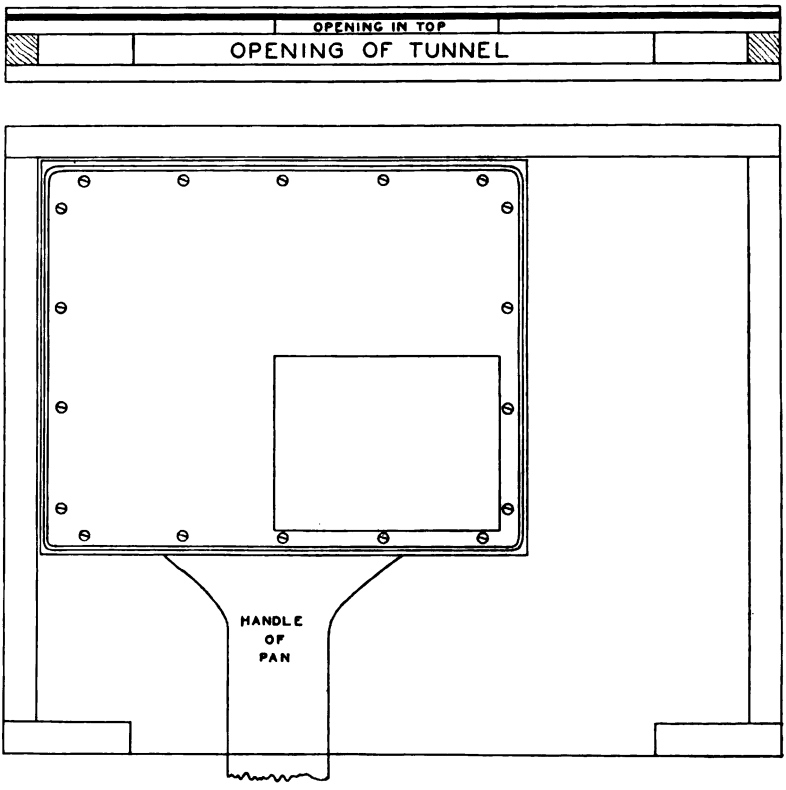

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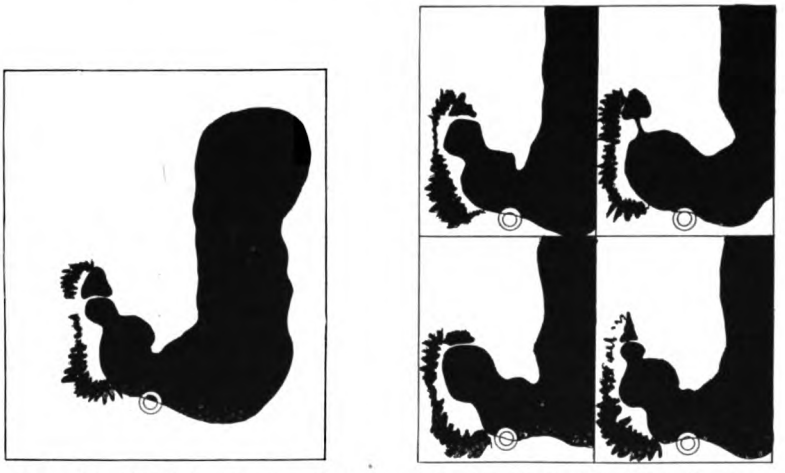

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[1] The author does not know who originally designed this apparatus.

opening in the tunnel (Fig. 147). Eight exposures, preferably on two 11- by 14-inch films, made at an interval of one minute or longer, are usually sufficient.

THE SMALL INTESTINE.

Except the duodenum and the terminal part of the ileum, little attention is paid to the small intestine in the usual roentgenologic examination of the gastrointestinal tract. Carman says that "practically the sole abnormality of the jejunum (and upper ileum) showing definite roentgenologic signs is obstruction." Mills attempted to draw conclusions from abnormalities in the appearance of the small intestine which he believed were due to derangements in the tension in the gastrointestinal tract. Morse and Cole have described a method of examining the small intestine and have written a description of its appearance on roentgenograms. The terminal ileum, because of its association with the appendix and cecum, is often secondarily involved in an infectious process originating in the appendix and should receive attention when the structures in the right iliac fossa are examined.

Morse and Cole say that a meal to be used in examining the small intestine must be of such composition and consistency that it will pass out of the stomach at a fairly uniform and rapid rate and that it must be of sufficient consistency to pass evenly—and preferably fairly slowly—through the intestine. They found that a mixture of 8 ounces by weight of barium sulphate and 5 ounces of water, making a moderately thick paste of about 7 ounces volume, is satisfactory. After ingestion of this mixture they make their usual routine examination of the stomach and duodenum, which requires about one-half hour. The examination of the small intestine proper consists of a 14- by 17-inch film exposed at the completion of the examination of the stomach and duodenum, and similar roentgenograms made two, four, and six hours after the ingestion of the meal.

From films exposed in this way they have described the arrangement of the coils and the appearance, but they have not published the results of the application of their method of examination in the detection of disease in the jejunum and upper ileum.

THE ILEOCECAL REGION AND APPENDIX.

Roentgenologic examinations of the ileocecal region and appendix are usually made for the purpose of detecting evidences of existing

or preceding inflammation in and around the appendix. It is for this purpose, as well as to determine delay in emptying of the stomach, that the sixth-hour examination is made. Quite often it is necessary to make an extra observation of these structures nine hours after the ingestion of the barium meal. This region also should receive attention at the twenty-fourth-hour examination and after the administration of the barium enema.

Normally the coils of the distal part of the ileum are located in the lesser pelvis, the terminal coil rising along the medial side of the cecum to end in the ileocecal junction. With the patient erect, the cecum extends over the brim of the small pelvis in slightly more than half the patients examined. The position of the appendix is variable. Usually extending toward the left, or toward the left and downward, it may extend in almost any direction from its attachment to the cecum. Sometimes it extends upward behind the cecum. In the change from the erect to the prone position all these structures, unless adherent, move upward for a variable distance, so that on films made in the prone position, the cecum is usually out of the pelvis in the right iliac fossa.

At the sixth-hour examination the normal position of the barium meal is in the terminal part of the small intestine, in the cecum, and in the ascending colon usually as far as its middle. The exact position of the meal depends on a number of factors. The rapidity of emptying of the stomach, the general tonus of the small intestine, the presence of inflammatory adhesions around the cecum and ileum, and the state of tone of the musculature of the colon are all conditions that will influence its position. Normally at nine hours the small intestine should be empty. According to Kantor a residue at this time indicates ileal stasis.

The greater part of the information at the sixth- and ninth-hour examinations must be obtained by fluoroscopy. It is only with the fluoroscope that fixation of the cecum, appendix, or ileum suggesting the presence of inflammatory adhesions can be determined. Also, it is only in this way that tenderness and muscular rigidity can be exactly located. From roentgenograms may be told the position, size, diameter, shape, etc., of the appendix, deformities of the cecum, and kinks in the terminal ileum.

Roentgenography of the ileocecal region is relatively simple. All films are made in the prone position, unless, to show a retrocecal or displaced appendix, it is necessary to alter the position of the patient. The highest point of the greater trochanter of the femur

is the landmark for placing films for exposures of this region (Fig. 148). It is nearly on the same level with the most inferior part of the small pelvis and is also in the lateral margin of the body, so that if the inferior lateral corner of the cassette is level with this point, the film will be in proper position. The tube should be centered so

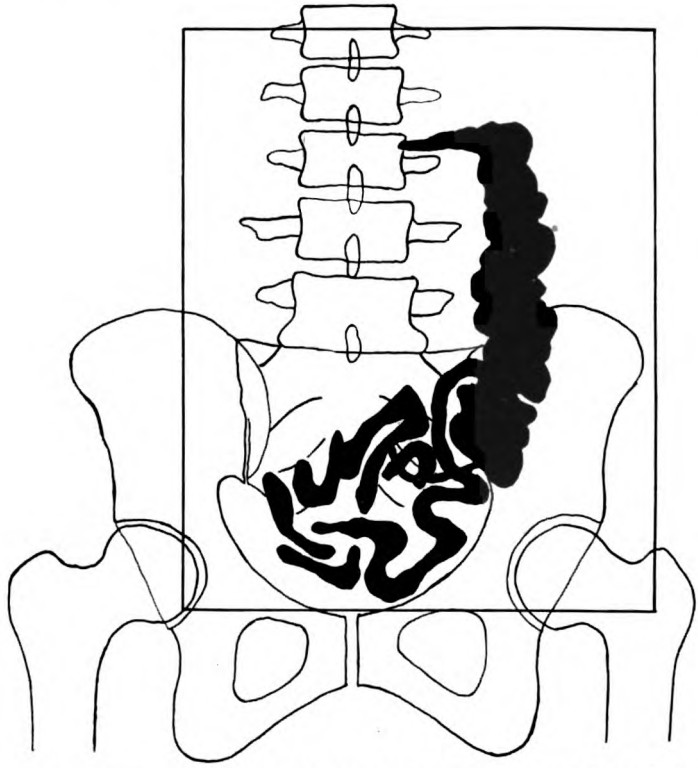

FIG. 148.—Postero-anterior view of the ileocecal region on a 10- by 12-inch film, patient prone, with the right inferior corner of the cassette level with the greater trochanter of the right femur.

that the central rays enter just below the highest point of the iliac crest. A film that is 10 by 12 inches in size will include all important structures.

THE LARGE INTESTINE.

Twenty-four hours after the ingestion of an opaque meal all the barium should be in the large intestine. Usually it is found scattered from the cecum distally into the descending colon. The

pelvic portion of the colon and the rectum will be poorly defined. The location of the barium is somewhat variable, depending chiefly on the degree of tone of the musculature of the colon. If a hypertonus or spasticity is present, the barium will usually be widely scattered in rather small masses; if the tonus is decreased, often it will be accumulated in a dilated cecum and ascending colon, the distal part reaching as far as the middle of the transverse portion.

At the twenty-fourth-hour examination the patient is examined for the position, size, and shape of the large intestine; the rate of progress of the barium mass and the tonus of the gut are determined; the cecum and appendiceal region are carefully palpated, and the filled portion is examined carefully for evidences of organic lesions, such as diverticuli, chronic ulceration, and carcinoma. Barium in the ileum at this time, with a normal emptying of the stomach, is an important indication of obstruction, usually from inflammatory adhesions, in the ileocecal region.

Examinations of a meal in the colon later than twenty-four hours often are made to determine the delay in emptying and its cause. Normally by the end of forty-eight hours the large intestine should be nearly empty of an ingested meal. Such examinations are usually made with the fluoroscope, films being made for purposes of record.

To complete a gastrointestinal examination, a barium enema is necessary. This is particularly important when organic lesions in the large intestine are sought. Before the enema is given, the colon must be rid of all fecal material and as much gas as possible. This is done by giving the patient a mild laxative the night before the examination, followed by a cleansing enema the next morning. Compound licorice powder seems to be the laxative preferred by many roentgenologists. The enema may be of soapsuds, plain water, or water containing 1 teaspoonful of baking soda to the quart.

The opaque enema should be fluid enough to pass readily through the enema tip, it should not be irritating, it should contain enough barium to render the colonic contents opaque, and it should be large enough to fill the entire colon. Carman recommends the use of 250 grams (about 8 ounces) of barium sulphate, 500 cubic centimeters of mucilage of acacia, and 2 or 3 cans of condensed milk to make a total quantity of 2 liters. At present there are commercial preparations in the form of powders that may be kept until required that are rather easy to prepare and make satisfactory enemas.

An enameled-ware enema can fitted with 5 to 6 feet of rubber

tubing, a cut-off clip, and a large size enema tip or small colon tube is satisfactory for injecting the enema. The tip need not reach farther into the rectum than well past the sphincters. A rubber syringe bulb in the tubing is often of considerable assistance in starting the enema or dislodging lumps that occasionally may occlude the tip.

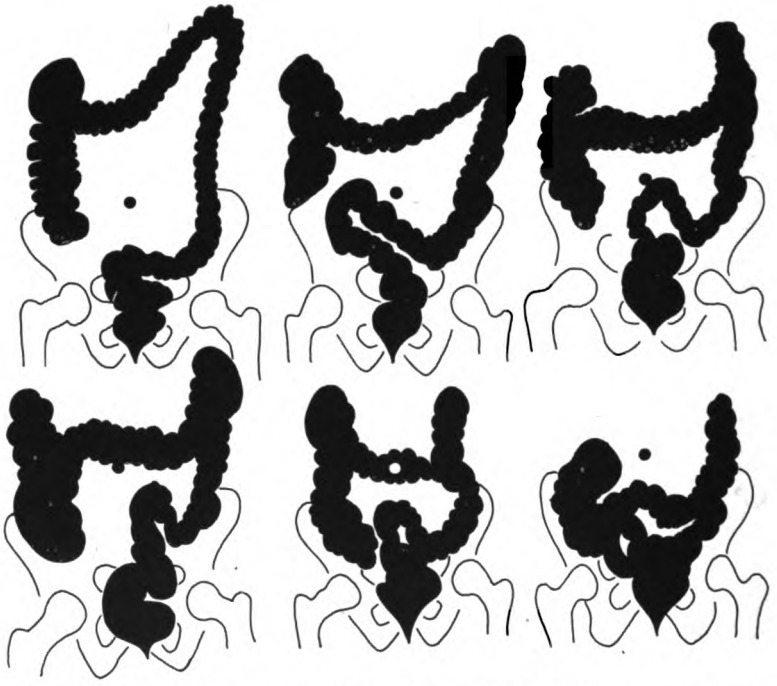

FIG. 149.—Postero-anterior views of the colon filled with a barium enema, showing some of the normal variations in size, shape, and position. For such exposures the inferior edge of a 14- by 17-inch cassette should be about 2 inches below the highest parts of the greater trochanters of the femora.

If the Roentgen-ray equipment includes a horizontal fluoroscope, it should be used in giving opaque enemas. The patient is placed in the supine position on the table, the tip inserted, with the can held at a height of not more than 2 or 3 feet above the table. The clip is released and the filling of the colon by the enema is observed with the fluoroscope.

Some little time is required for the rectal ampulla to fill. There will be a delay in the passage of the enema out of the small pelvis, following which the colon as far as the splenic flexure will fill rapidly.

At the splenic flexure, when the colon passes anteriorly across the vertebral column, and again at the hepatic flexure, there will be other periods of delay. By the time the enema has reached the cecum all parts distal to it will be well filled. While the enema is being injected, a careful search of the entire colon is made for evidences of disease.

At least one film of the colon should be made for purposes of record. Since the loop of colon that crosses the inlet of the pelvis on the left side will be incompletely filled in the supine position, the patient should be turned to the prone position for this film. For picturing the entire colon a 14- by 17-inch film is required. The lower border should be located about 2 inches below the superior parts of the greater trochanters of the femora or about the same distance below the tip of the coccyx (Fig. 149). The central rays should be directed into the vertebral column just above the superior parts of the hip bones. Smaller films of parts of the colon in either the supine or prone position may be made in addition to the large film of the entire colon.

When the examination of the filled colon has been completed, the patient is permitted to discharge as much as possible of the enema. This is followed by a fluoroscopic examination, and films if indicated, to determine the emptying of the large intestine. This completes the examination.

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CHAPTER XIX.

THE URINARY TRACT.

THE urinary tract includes the kidneys, ureters, the urinary bladder, and the urethra. The shape of the kidneys is too well known to need description. Each kidney is about 4 inches in length, 2½ inches in width, and 1½ inches thick. The left is usually slightly longer and more slender than the right. They are located in the upper posterior part of the abdominal cavity. The upper pole of each kidney is usually at the level of the body of the twelfth thoracic vertebra; the lower is at the level of the body of the third lumbar vertebra (Fig. 150). The left is slightly higher than the right, its upper pole reaching the eleventh rib while that of the right reaches as high as the twelfth rib or eleventh intercostal space. The long axes of the kidneys are not directed vertically but they incline from above laterally and inferiorly nearly parallel with the edges of the psoas muscles.

There is some variation in the positions of the kidneys depending on body architecture. As a rule they are somewhat higher in those of the hypersthenic than in those persons who are of asthenic habitus. This is not so marked as are the variations in different parts of the gastrointestinal tract. There is some movement of the kidneys with respiration which is estimated to be from ½ to 1½ inches. There is also a slight displacement downward in the change from the supine to the erect position. Movements of these kinds are slightly more pronounced on the right than on the left side.

In a majority of instances the kidney pelvis is located at the level of the space between the transverse processes of the first and second lumbar vertebræ. The junction of the kidney pelvis and the ureter is most often at the level of the transverse process of the second lumbar vertebra (Fig. 150). From this point each ureter extends downward with a slight inclination medially, crossing the transverse processes of the third, fourth, and fifth lumbar vertebræ, crossing each process slightly nearer the midline than it does the one just above. As seen in roentgenograms the normal ureter may be straight or slightly wavy in its abdominal course. It enters the

pelvis anterior to the sacroiliac joint to pass downward, forward, and slightly farther medially to enter the bladder at about the horizontal level of the spine of the ischium (Fig. 150).

The position of the urinary bladder depends largely on its degree of distention. As a rule it may be stated that in adult males the level of the trigone, the most fixed and inferior portion, is that of the

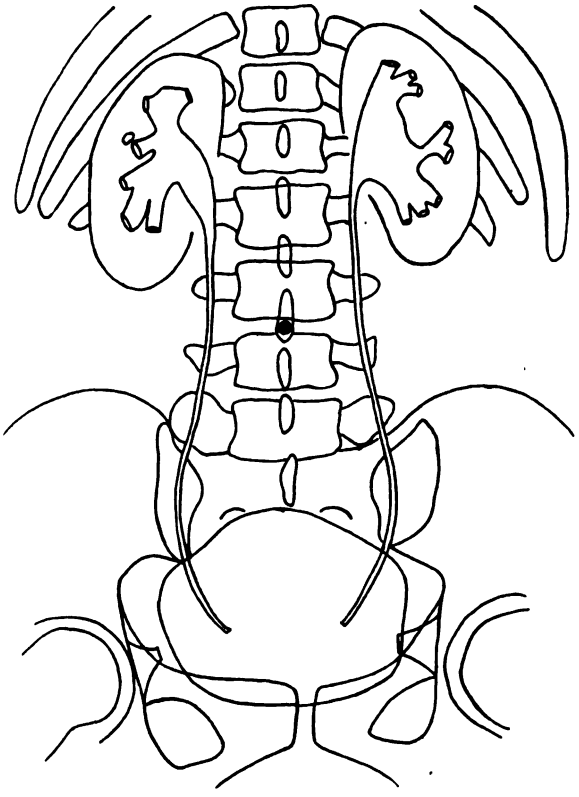

FIG. 150.—Drawing showing different parts of the urinary tract.

middle of the symphysis pubis, and in adult females that of the inferior limit of the symphysis. Distention raises the superior surface above the symphysis for a variable distance. In infants and young children the bladder is located higher, being all above the pubes and therefore, in location, an abdominal organ.

The density of the kidneys is slightly greater than that of the surrounding structures. Their density is sufficient that, under

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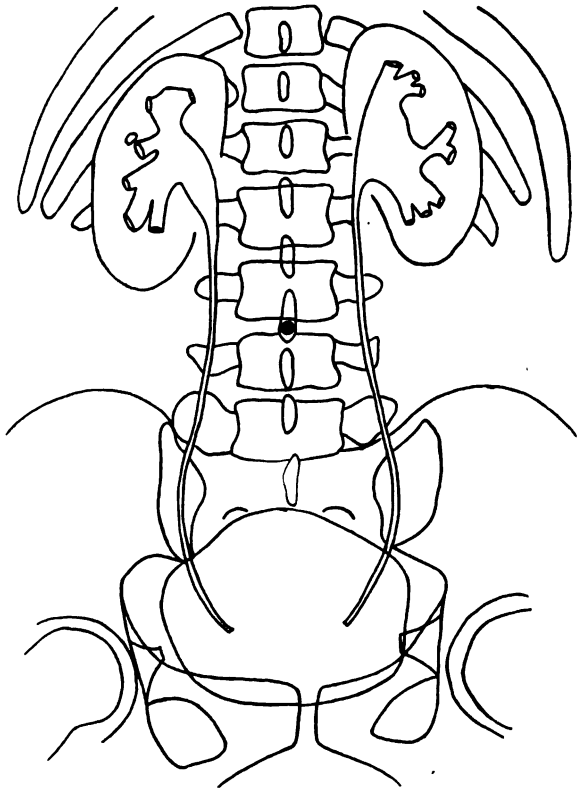

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The density of the kidneys is slightly greater than that of the surrounding structures. Their density is sufficient that, under

certain conditions, their outlines can be shown on roentgenograms through nearly their entire extent. This makes it possible by means of roentgenography to determine their size, shape, and position, their relative density, and the presence of calcareous and other deposits in the form of calculi. With the assistance of the urologist in the performance of pyelography, much other important information with reference to renal disease may be obtained.

Roentgenography of the ureters is usually undertaken to determine the presence of ureteral stones. By the injection of an opaque solution, dilatations and abnormalities in diameter, outline, and course can be detected. Roentgenograms of the bladder are made for calculi and, after injection either with an opaque solution or air, for the presence of tumors, diverticuli, etc.

The preparation of the patient for roentgenography of the urinary tract is often a problem. While it is quite true that the most satisfactory films are obtained when the patient's intestinal tract is free from fecal material and gas and when the stomach is empty, it is also true that these conditions sometimes cannot be obtained and that efforts to secure them may defeat their own purpose. If preparation is deemed advisable, it is best to have the patient refrain from eating, take a cathartic either of castor oil or some vegetable preparation, compound licorice powder for example, the night before, and an enema on the morning of the examination. Even then, if the enema is properly administered, enough of it may be retained to fill the transverse colon with fluid, which is more objectionable than the feces and gas it usually contains.

Too often requests for examinations of the urinary tract are made and the patient received during or immediately after an attack suspected of being renal colic. Since morphine is used for the relief of pain during such attacks, the large intestine is filled almost always with gas that it is very difficult to dislodge. If cathartics and enemas fail, it may be necessary to make a reëxamination of some of these patients after the effect of the opiate has subsided.

Routine examinations should include the entire urinary tract. Calculi are often multiple and found in both kidneys, or in the kidney and ureter of either the same or the opposite side; pain perceived by the patient in one side may be caused by a calculus in the other side. At least two films are necessary, one to show the kidneys and the upper parts of the ureters, the other for the lower parts of the ureters and the bladder. Often more than two films are required. These may be needed for stereoscopic films of either the upper or lower

parts of the tract, for views in the transverse direction, or for two films in different positions for the bladder.

For roentgenography of the urinary tract a Potter-Bucky diaphragm is very desirable. The patient should be placed on the diaphragm in the supine position with the head well supported and the knees elevated. For the film of the upper part of the tract the patient is so placed that the tube, centered over the central point of the diaphragm, is from 1 to 2 inches above the navel. The film, of the 14- by 17- or 11- by 14-inch size, is placed with its upper margin reaching about 2 inches above the antero-posterior level of the sternoxiphoid junction (Fig. 151).

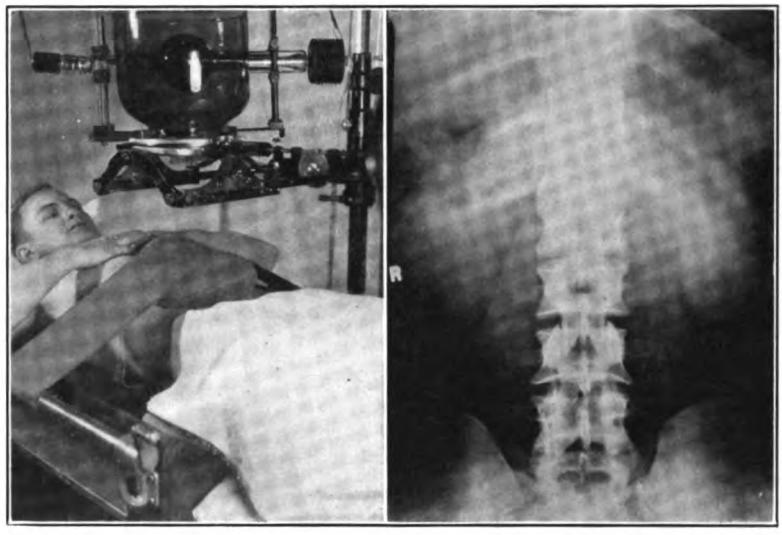

FIG. 151.—Antero-posterior exposure of the upper part of the urinary tract. The tube is centered over the midline 1 to 2 inches above the navel.

In kidney roentgenography it is advisable to use compression. This assists in immobilizing the kidneys, preventing motion from involuntary respiratory movements, and forces the air-filled portions of the colon into the lateral parts of the abdomen so that their shadows are not over those of the kidneys. A partially inflated rubber basketball bladder placed under the compression band of the diaphragm is satisfactory for this purpose.

Since the kidneys move from $\frac{1}{2}$ to $1\frac{1}{2}$ inches with each respiration, depending on its depth, respiration should be stopped during the exposures. Only under rather rare conditions should the exposure

time exceed five seconds; and, with thin patients, it may to advantage be as short as two and one-half seconds.

For a single routine film of the lower part of the urinary tract, except for the position of the patient, the procedure is the same as the above. The tube is centered over a point joining the upper two-thirds with the lower third of the distance between the umbilicus and the symphysis pubis. The cassette and the patient should be placed so that the lower margin of the film is about 2 inches below the highest points of the greater trochanters of the femora. While compression is not as essential as for the upper part of the tract, better films will be obtained if it is used (Fig. 152).

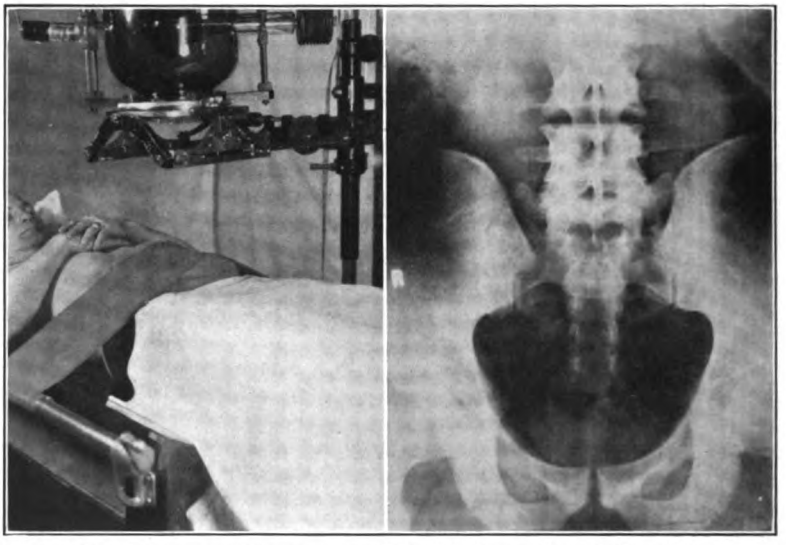

FIG. 152.—Antero-posterior exposure of the inferior portion of the urinary tract. The tube is centered over a point at the junction of the upper two-thirds with the lower third of a line extending from the umbilicus to the symphysis pubis.

In many laboratories stereoscopic films at least of the upper part of the urinary tract are made as a routine procedure. A tube shift along the mid-sagittal plane of the body is preferable. After the patient, film, and tube have been arranged as described above for a single film, if the tube is shifted $1\frac{1}{4}$ inches toward the feet, the setting will be correct for the exposure of the first film. After it has been exposed, the patient is permitted to breathe quietly but should not move while the cassette is being changed and the tube shifted $2\frac{1}{2}$ inches toward the head for the second film.

When a search is being made especially for stone in the urinary bladder, it often is advisable to make an exposure through the pelvis with the patient in the prone position. For this, the patient is placed with the symphysis below the center of the diaphragm. The cassette is placed with its lower margin at the level of the tops of the greater trochanters. The tube should be tilted upward to throw the shadow of the bladder above the symphysis. A tilt of 15 degrees is sufficient. This is permissible with a Potter-Bucky diaphragm as long as there is no lateral displacement of the tube. The central rays should be centered over the middle of the supero-inferior extent of the gluteal fold (Fig. 153).

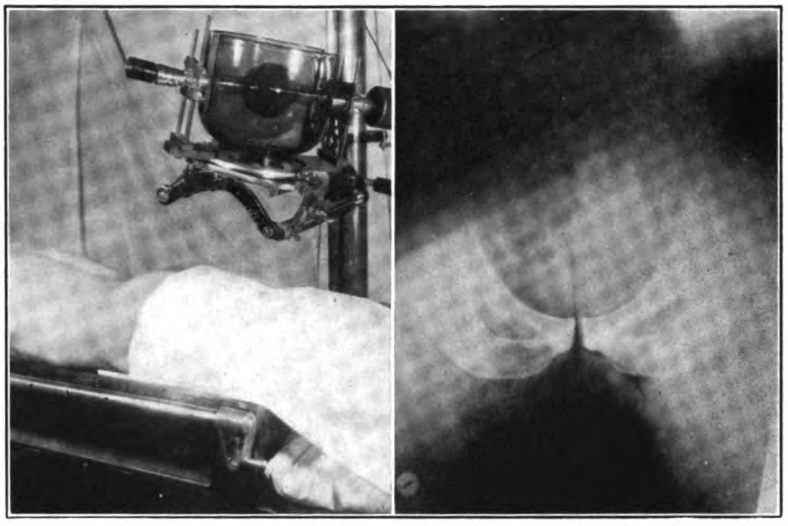

FIG. 153.—Postero-anterior oblique exposure of the urinary bladder. The patient is placed so that the shadow of the pubis will fall below the middle of the film, the tube is moved toward the inferior part of the Potter-Bucky diaphragm and tilted upward at an angle of 15 degrees. The central rays enter through the middle of the gluteal fold.

Roentgenography of the urinary tract without the aid of a Potter-Bucky diaphragm is more difficult. To obtain the best results, a number of exposures should be made using a small cone and relatively small films. One exposure should be made for each kidney and the upper part of each ureter, one for the middle portions of the ureters and one for the lower parts of the ureters and the bladder, making four exposures in all (Fig. 154).

For the films of the kidneys the tube is centered so that the central

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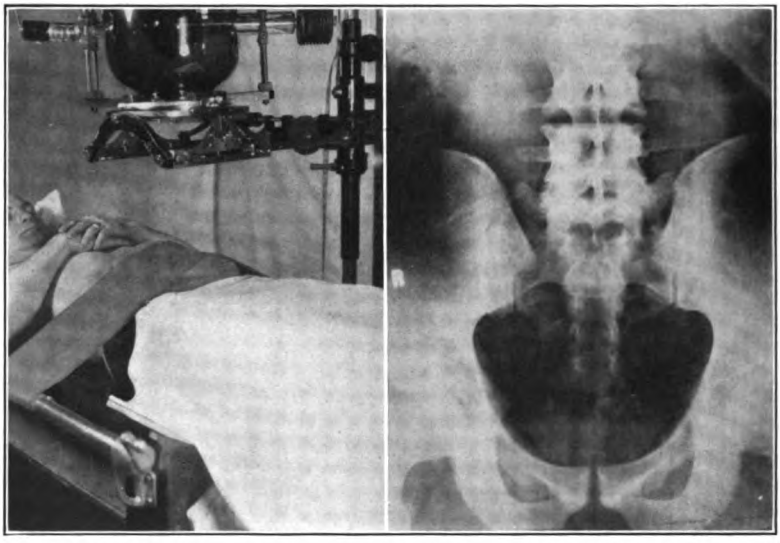

FIG. 152.—Antero-posterior exposure of the inferior portion of the urinary tract. The tube is centered over a point at the junction of the upper two-thirds with the lower third of a line extending from the umbilicus to the symphysis pubis.

In many laboratories stereoscopic films at least of the upper part of the urinary tract are made as a routine procedure. A tube shift along the mid-sagittal plane of the body is preferable. After the patient, film, and tube have been arranged as described above for a single film, if the tube is shifted $1\frac{1}{4}$ inches toward the feet, the setting will be correct for the exposure of the first film. After it has been exposed, the patient is permitted to breathe quietly but should not move while the cassette is being changed and the tube shifted $2\frac{1}{2}$ inches toward the head for the second film.

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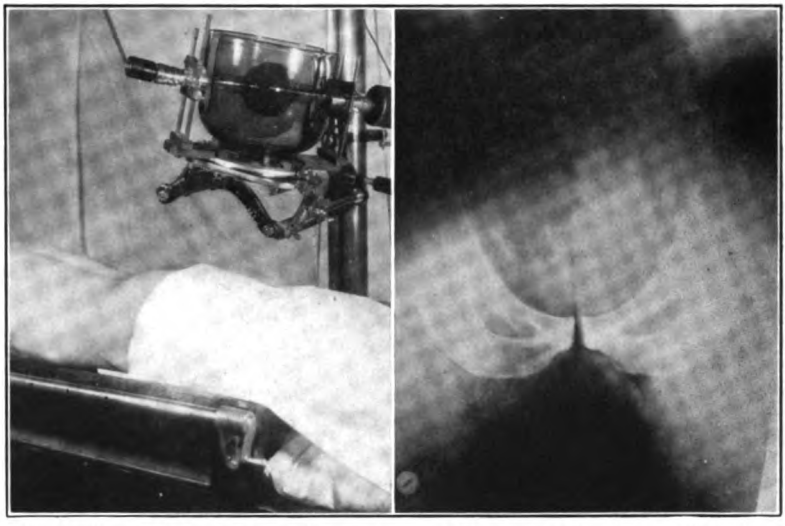

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For the films of the kidneys the tube is centered so that the central

rays are directed into a point halfway between the sternoxiphoid junction and the umbilicus and from 2 to 3 inches lateral to the midline of the body. An upward tilt of the tube of 5 degrees and com-

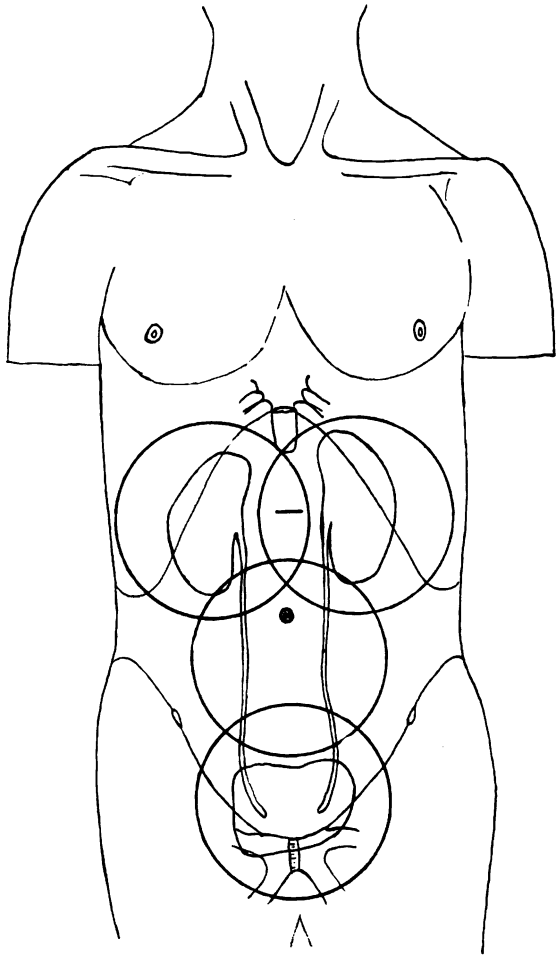

FIG. 154.—Showing the areas to be included on small films of the urinary tract exposed without a Potter-Bucky diaphragm.

pression of the cone of the tube stand against an inflated rubber bag are of considerable aid. For the film of the middle portions of the ureters the tube should be placed over the umbilicus with the rays directed perpendicularly to the table top and the film placed

accordingly. For the view of the bladder the tube should be centered over a point midway between the umbilicus and symphysis pubis and tilted toward the feet at an angle of 5 degrees. The cassette is placed so that the lower margin of the film is about 2 inches below the tops of the greater trochanters.

For small films of different parts of the urinary tract a small cone should be used. Since compression always is necessary, the cone should be large enough to cover just the region being examined at the distance resulting when the pressure of the cone against the rubber bag is applied. A cone with a diameter of 5 inches at the large end is satisfactory. The anode-film distance may be controlled to a limited extent by the degree of inflation of the compression bag.

Urography is a term used by Braasch to designate a study of the different parts of the urinary tract made artificially opaque by the injection of pyelographic and other media. Under this heading are included pyelography, ureterography, cystography, and urethrography. For the first of these, the examination of the pelves of the kidneys and the ureters, the injections must be done by a physician skilled in the use of the cystoscope, working in conjunction with the roentgenographic technician. For the examination of the bladder and urethra, neither special instruments nor special training are required.

There is very little difference in the roentgenography involved in ordinary urinary tract examinations and that used in urography. A special table equipped with a Potter-Bucky diaphragm is very desirable for urographic work, but they probably are not used except in large hospitals and clinics where numbers of such examinations are made. It is doubtful if a diaphragm can be placed on the ordinary examining table and made to work satisfactorily. For pyelograms and ureterograms with the special table the technique as given above for examinations with the Potter-Bucky diaphragm will be satisfactory. For those made on the ordinary examining table, multiple exposures should be made, each including but a small area, as given above for examinations when a diaphragm is not available.

The following is the technique given by Braasch for examination of the urinary bladder by means of cystography: The bladder is filled through a catheter with a 5 per cent emulsion of silver iodide and the catheter withdrawn. The table is tilted at an angle of 10 degrees toward the feet. The Roentgen-ray tube is also tilted 5 degrees toward the feet of the patient, making the angle of the

incident rays 15 degrees in all. The tube is also tilted 8 degrees and so centered that the rays pass tangentially along the side of the bladder, entering anteriorly and passing medially as well as downward. Two films are exposed in this way, one of each side of the bladder. The catheter is then reintroduced and as much of the solution as possible is removed. In emptying no pressure should be made with the hand on the abdomen over the bladder. When emptied, the third film is taken. This is an antero-posterior view maintaining the downward tilt of the table and tube but without the lateral angulation of 8 degrees. Compression should not be used with any of these exposures.

Pfahler uses air in cystography. In his method a sterile catheter is introduced and the bladder filled with air by means of an atomizer bulb. Films are made in the antero-posterior and postero-anterior positions as previously described. The air is removed through the catheter.

Urethrography is so limited in its usefulness that the technique will not be included. Those who are interested are referred to the excellent work of Braasch.

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CHAPTER XX.

MISCELLANEOUS EXAMINATIONS.

LOCALIZATION OF FOREIGN BODIES.

In wartime roentgenology the localization of foreign bodies makes up one of the major duties of army roentgenologists and demands methods and apparatus for the rapid and accurate performance of this work. Except possibly in connection with a few industries, the civil roentgenologist only occasionally is asked to make an accurate localization of metallic substances in the body. Pieces of needles and small fragments of metal in the extremities, bullets in gunshot injuries, and metallic foreign substances in the eyes are the more common metallic bodies the roentgenologist is requested to locate. For such examinations as are made in the average Roentgen-ray laboratory special apparatus rarely is necessary, it being possible to make rather accurate localizations with the usual fluoroscopic and roentgenographic equipment. A comprehensive discussion of this subject is given in the United States Army *X*-ray Manual and in the articles listed in the bibliography at the end of this chapter.

An examination for the localization of a foreign body usually should be begun with a preliminary fluoroscopy. Since bullets often take an unexpected path in the body, are frequently found at a distance from their place of entry, and occasionally break up into two or more fragments, this is particularly important in gunshot injuries. For pieces of needles or small bits of metal in the extremities, the fluoroscopy is not so important, for such substances rarely travel far from their place of entrance.

During the fluoroscopic examination, by rotating the patient or the extremity, by making observations at right angles to each other, finding the position which shows the object nearest the skin surface and estimating its depth, by marking on the skin either the point nearest which the object is located, or two points, one in an antero-posterior and the other in a lateral direction projections from which would cross at the location of the object, by observing the movements caused by palpation over it, and by determining the position

with reference to parts of bones or other landmarks, it is often possible to make a very accurate statement of the position of the foreign body from the fluoroscopic examination alone.

To obtain a permanent record of the position of the body for the use of the surgeon should he wish to attempt its removal, roentgenograms should be made. Two views should be taken which are as nearly as possible at right angles to each other, one to show the position in an antero-posterior plane and the other to show its location in a lateral plane (Fig. 155). In reporting on these films it is

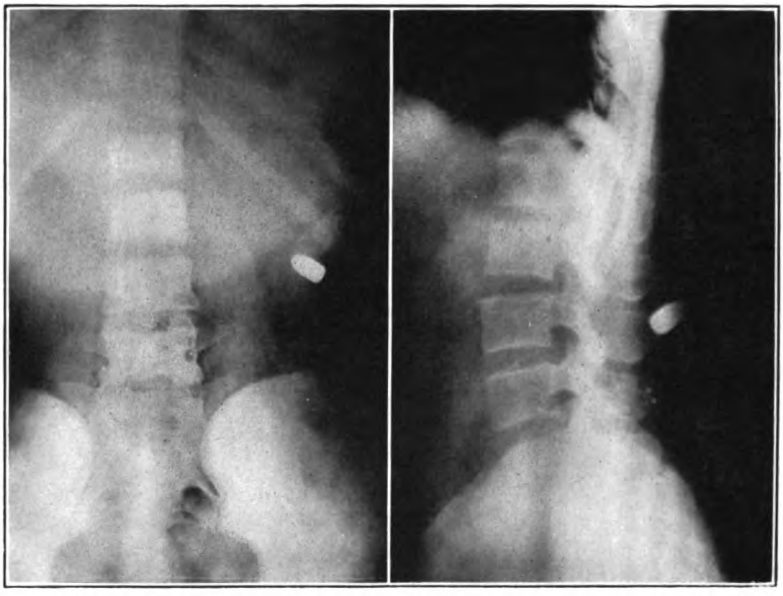

FIG. 155.—Antero-posterior and lateral roentgenograms of a gunshot injury of the back. The bullet entered on the right side, passed through the spinous process of the fourth lumbar vertebra and lodged in the soft tissues. From these films the bullet could be located so accurately that its removal was easy.

important to state the positions of the patient when the films were exposed; it is also important to include the fluoroscopic findings and an accurate anatomical location of the foreign body.

Should it be advisable to determine the exact depth of the foreign body, this may be done by making a double exposure on a single film, using a definite procedure which permits of a calculation of the depth of the object. First, make a fluoroscopic examination and find the point on the skin nearest the foreign body. Make a mark directly over it and determine the position of the patient which

places it nearest the fluoroscopic screen. Then place the patient in a similar position for the exposure, substituting the cassette and film for the screen, with the cassette in direct contact with the patient's body. Place the tube directly over the foreign body, accurately measure the distance from the cassette to the tube anode, make an exposure of about one-half the normal for that region,

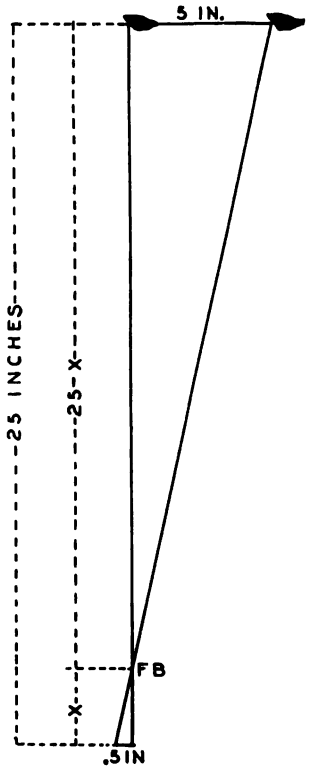

FIG. 156.—Diagram illustrating the method of determining the depth of a foreign body by means of a double exposure, as described in the text. FB, foreign body.

shift the tube a known distance along the arms of the tube stand, and make a second exposure similar to the first. The patient must remain immobile from the beginning of the first to the end of the second exposure, and, if the object is in the thorax or abdomen, must suspend respiration during that time. When developed, a film exposed in this manner will show two images of the foreign body.

By taking the known anode-film distance, the length of the tube

shift, and determining from the film the distance between identical points of the images of the foreign body, enough figures are obtained to make an accurate calculation of the depth of the body from the skin surface. This calculation is based on the fact that the tube shift, the projection of the rays through the body for the two exposures, and the distance between the two images on the film make two similar right-angle triangles, the sum of the heights of which is the known anode-film distance (Fig. 156).

For example, in a case in which the anode-film distance is 25 inches, the tube shift is 5 inches, and the distance between identical parts of the two images is 0.5 inch, the following is a method of determining the depth of the body. This calculation is based on the fact that parts of similar right-angle triangles are proportionate to each other. It will be seen from Fig. 156 that two similar triangles are formed. The height of both is 25 inches, the height of the smaller is represented by x, and that of the larger by $25\text{-}x$. The base of the larger is 5 inches; that of the smaller is 0.5 inch. From these figures the following proportion is obtained.

$25\text{-}x:5::x:0.5$, multiplying the means and the extremes gives $5x = 12.5 - 0.5x$, changing the sign of the -0.5x and transposing it to the other side of the equation gives $5.5x = 12.5$, or $x = \frac{12.5}{5.5}$ or $x = 2.27$ which is the depth in inches of the body from the skin.

The same result will be obtained by using the following formula which is given in the article by Case. Depth $= \frac{b \times h}{a + b}$, when a is the distance the tube is shifted, h the distance between the screen or film and the anode of the tube, and b the distance of the shift of the shadow of the projectile or foreign body. Substituting in this formula gives depth $= \frac{0.5 \times 25}{5 + 0.5}$ or $\frac{12.5}{5.5}$ or 2.27 inches.

Fluoroscopy is of considerable value in the removal of foreign bodies, the roentgenologist or technician often being called upon to assist the surgeon in such work. First the location of the body is determined by fluoroscopic examination and the skin surface nearest to it is found. A mark is made directly over the foreign body to assist the surgeon in making the skin incision. Ink, mercurochrome, tincture of iodine, or silver nitrate reduced with a drop of developer (as suggested by Holmes and Ruggles) may be used

for this purpose. When possible, in the removal of a piece of needle, the mark and the skin incision should be made at right angles to the foreign body. The room lights may then be turned on and the skin incision made, the Roentgen-ray worker keeping the eyes protected so as to preserve the accommodation for further fluoroscopy, should such be necessary. If the preliminary search is unsuccessful, a fine-pointed curved hemostat may then be introduced into the wound and the fluoroscopy continued. By moving the hemostat from side to side and observing the movements of the foreign body, by increasing or decreasing the depth of the hemostat in the wound, and by rotating the part to permit of observations at different angles, the body can be approached and grasped with the hemostat. Since the proper accommodation of his eyes has been preserved, and since he is accustomed to fluoroscopic observations, this usually can be done better by the roentgenologist than by the surgeon. When once grasped, the removal of the foreign body is a simple procedure.

Occasionally a roentgenologist is asked to locate a foreign body in the air passages or in the alimentary canal. Little difficulty should be experienced in case the substance is of a metallic nature. By fluoroscopy in different positions and by postero-anterior and lateral roentgenograms, metallic foreign bodies in the air passages can be located. A body, such as a pin or coin, in the alimentary canal can be located by administering a barium meal and finding its position with reference to the barium as it passes through the canal.

Roentgenologic examination is of considerable value in determining the presence of non-opaque substances in the air passages and in the esophagus, but it is not of much value in the rest of the alimentary canal unless the body be of rather large size. In the air passages a non-opaque substance will cause an obstructive emphysema, a lung abscess, or a complete obstruction with an area of massive collapse in the lung supplied by the obstructed bronchus. Because the inspiratory effort is greater than the expiratory, if the obstruction from a non-opaque foreign body is incomplete, an obstructive emphysema will result in a part of one lung, in an entire lung, or in both lungs, depending on whether the body is in a smaller bronchus, a main bronchus, or in the trachea. In this condition the emphysematous lung tissue will be larger than normal in volume, causing changes from normal in the position of the diaphragm and mediastinum, and, when there is an emphysema of both lungs from a body in the trachea, a reversal of the normal in

the respiratory changes in the size of the heart shadow. These changes have been observed and described by Manges.

The roentgenologic examination for a non-opaque foreign body in the air passages consists of fluoroscopy and the exposure of antero-posterior or postero-anterior films, one at the end of expiration and one at the end of inspiration. The fluoroscopic and roentgenographic images are studied for the changes indicated above.

In examining for non-opaque foreign bodies lodged in the esophagus Manges recommends observations during the drinking of bismuth and barium mixtures and during the swallowing of gelatin capsules filled with bismuth subcarbonate. Capsules, thoroughly wet and increasing from smaller to the 00 size, may be used. Interference with the passage of the capsules and the coating of the body with bismuth after dissolution of the gelatin, as seen on the fluoroscopic screen and on antero-posterior and lateral roentgenograms, assist in determining the size, shape, location, and nature of the foreign material.

The accurate localization of foreign bodies in the eyeball requires a Sweet-Bowen apparatus, which should be part of a Roentgen-ray equipment where much such work is done. The directions for the use of this apparatus accompany it or can be obtained from the United States Army *X*-ray Manual, making it unnecessary to give them here. By careful examinations valuable, though not absolutely accurate, information can be obtained in those rare cases of foreign bodies in the eye that come to everyone doing roentgenologic work.

It is first necessary to determine whether a foreign body actually is located within the eyeball; some of those that enter through the cornea pass entirely through the globe and lodge in the orbit. The preliminary examination may be made with the fluoroscope or by exposing a film. If the body is large enough to be seen with the fluoroscope and it moves from side to side or up and down with the movements of the eye, the exposures for its localization may be made. If it cannot be seen with the fluoroscope, films must be exposed.

Film exposures are made in the following manner: First take a thin strip of lead rubber, sheet lead, lead foil, malleable wire or other radiopaque material about 1 inch in length and fasten it with small strips of adhesive plaster to the eyelid of the injured side in a vertical position, over the cornea. A small piece of the same material may be fastened to the middle of the strip and placed as nearly as possible directly over the cornea which is located $\frac{1}{8}$ to $\frac{1}{4}$

inch above the margin of the upper eyelid when the eyelids are closed. Place the patient in the lateral position on the table with the sagittal plane of the head parallel with the table top (see Fig. 93) with the injured eye down and with the uncovered half of a small cassette under the orbits, the other half being covered with sheet lead or lead rubber. Focus the tube so that the central rays pass directly through the orbits and make an exposure with the patient looking, with the uninjured eye, at an object at the same height as the eye and directly in front of it (Fig. 157, A). Change the cassette so that the unexposed portion is under the orbits with the exposed portion protected. Have the patient look at an object at the same level as the eye but above his head and make half a full exposure. Without moving the position of the head, then have him look at an object below the level of the eyes and make another half exposure on the same film (Fig. 157, B).

Similar exposures may then be made in a postero-anterior direction, one with the patient looking toward the floor, and a second double exposure with the patient looking first toward the right and then toward the left (Fig. 157, C and D). A position similar to that of the Caldwell position for nasal accessory sinuses (page 274), except that the rays should be directed through the orbit, is about correct for such exposures.

When developed, examination of films exposed in this manner will give a good idea of the location of a metallic foreign body within the orbit. If there is a double image on the double exposures, it is in the eyeball or some other orbital structure that moves with the eyeball. Since the globe of the eye moves within the fascia bulbi (capsule of Tenon), without moving the other orbital structures, except the muscles, double images would be nearly positive proof of the presence of the body in the eyeball. By allowing from 2 to 4 millimeters for the thickness of the eyelid and measuring the distance of the shadow behind that of the opaque strip on the lateral views, the approximate depth of the foreign body can be determined. From the postero-anterior views and from the arcs of a circle made by the foreign body on the double exposures, the location of the body with reference to the quadrants of the eyeball, the anterior and posterior hemispheres, etc., may be determined.

A more accurate method of localization that does not require accessory apparatus has been described by Patton. This is by means of contact localizers attached to the conjunctiva of the eyeball near the upper and lower corneal margins. Patton says that the

objection to the use of other methods of localization is that there is no way of checking the position of the eyeball at the instant of exposure if the globe may move independently of the opaque marker.

He suggests that the opaque localizers, in the form of small rings, 2 millimeters in diameter, be made by bending No. 26 soft silver suture wire around the points of small tissue forceps and cutting it off with scissors, leaving the rings open. After cocainization of the conjunctiva, it is grasped about 3 millimeters from the margin of the cornea and the rings applied, one above and one below the

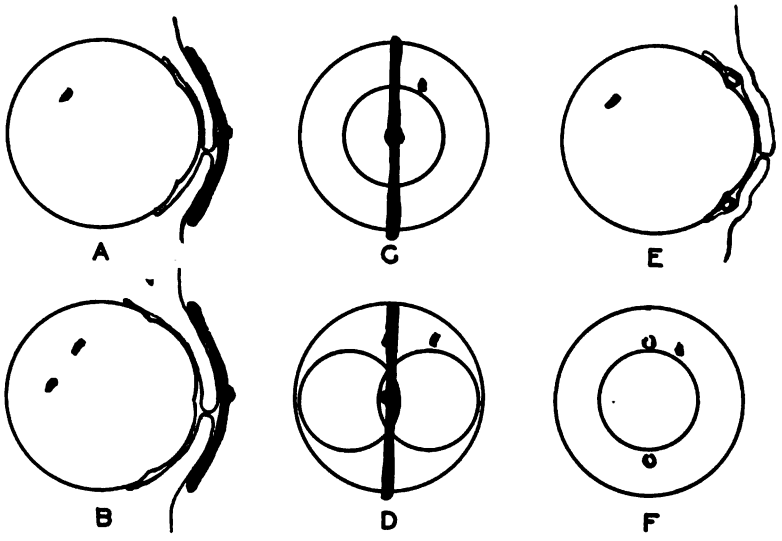

FIG. 157.—Schematic drawings illustrating the methods of localizing metallic foreign bodies in the eye. A, lateral view with an opaque strip on the eyelids; B, double exposure on a lateral view with an opaque strip on the eyelids; C, postero-anterior view similar to A and B; D, double postero-anterior exposure with opaque strip on the eyelids; E and F, lateral and postero-anterior views with contact localizers attached to the conjunctiva as suggested by Patton.

pupil, by clamping them over the conjunctival folds between the forceps and the corneal margin. A piece of silver wire or sliver of sheet lead clamped around a fine silk suture will serve the same purpose, if the suture be passed through the conjunctiva as near the corneal margin as possible and tied so that the marker is in contact with the conjunctiva. Markers of this kind can easily be removed by cutting the ring or the suture, the slight corneal trauma being of no consequence. Roentgenograms should be made in the postero-anterior and lateral positions with the markers in place (Fig. 157,

E and F). By measuring from the shadows of the markers to those of the foreign body in the two views an accurate localization of the position of the latter may be made. Patton recommends that contact localizers be used with the Sweet-Bowen apparatus to make certain that the eyeball is in the correct position at the time of the exposures.

In making measurements of the location of a foreign body within the orbit, it should be remembered that the diameters of the eyeball are from 23 to 24.5 millimeters—slightly less than 1 inch—and that there is a variation of as much as 3 millimeters in the diameters of the eyeballs of different persons.

If there is any likelihood that a foreign body has passed through the eyeball and lodged in the sclera or in the orbit, enucleation never should be done because of the foreign body alone, without localization with a Sweet-Bowen apparatus, if it is possible to get the patient to a roentgenologist equipped to do such work.

ROENTGEN-RAY EXAMINATIONS DURING PREGNANCY.

It has been said that the demonstration of the shadows of fetal bones on roentgenograms is the earliest demonstrable positive sign of pregnancy. Fetal bones have been shown as early as the twelfth and thirteenth weeks of a normal pregnancy; they are often shown by the end of the sixteenth week, and they should be shown with but few failures during the twentieth week and thereafter. In addition to the diagnosis of pregnancy, the use of Roentgen-ray films to determine the position of the fetus, to determine the presence of a multiple pregnancy, and to determine fetal abnormalities and even fetal death, is on the increase. Cases have been reported of the successful diagnosis of an abdominal pregnancy at term by means of roentgenographic examinations.

Films made for the purpose of diagnosing pregnancy, particularly if early in its course, should be of the very best quality, a great amount of detail and contrast being desirable. The patient should be prepared for the examination by the administration of one or more enemas to rid the rectum and pelvic colon of gas and fecal material, and the bladder should be emptied. A Potter-Bucky diaphragm should always be used. The suspension of respiration during exposures is essential. Various positions have been used for the exposure of the films. Direct postero-anterior, antero-posterior, and oblique exposures have been used with the rays

directed either from above or from below in the sagittal plane. On films made in the direct postero-anterior or antero-posterior projections the shadows of the sacrum and the fifth lumbar vertebræ are apt to obscure those of the uterus and its contents. To overcome this objection, Stein and Arens recommend a dorsal posture with an increased lordosis produced by placing sand bags or pillows under the lumbar spine. The rays are directed from above downward in the axis of the superior strait. Thoms, in Roentgen pelvimetry, to have the superior pelvic strait parallel with the film, locates the

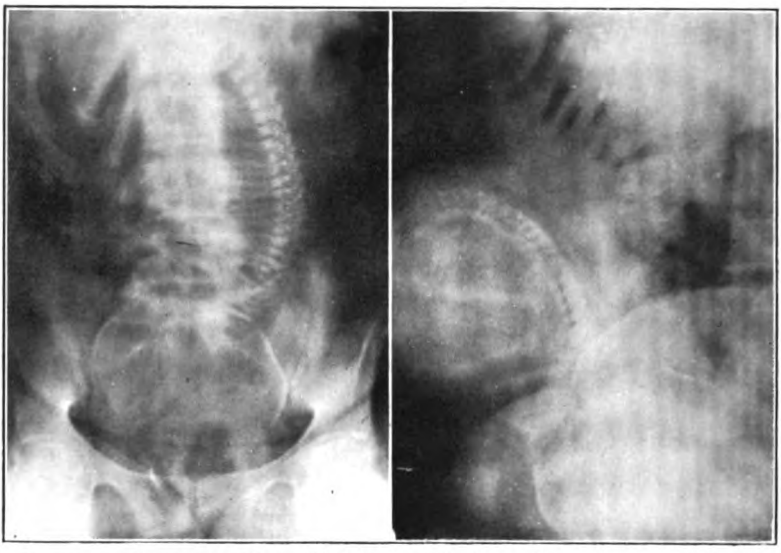

FIG. 158.—Postero-anterior and right lateral views of a pregnancy near term to determine the position of the fetus. In this case the position is occiput left posterior.

strait by means of a plane extending from the upper and anterior border of the symphysis pubis to the space between the fourth and fifth lumbar vertebræ posteriorly. The central rays are directed into the pelvis 5 centimeters posterior to the upper border of the symphysis. An oblique exposure from below upward may be made by using the technique described for films of the bladder in the prone position (see page 355 and Fig. 153). As in other examinations, more reliable conclusions follow the study of several films exposed with the patient in different positions. Probably the most constant and important finding on films early in pregnancy is the shadows of

the centers of ossification for the bodies of the vertebræ, appearing in a curved row, not unlike a short string of small beads.

Films made in the later months of pregnancy may be exposed with the patient in the prone, supine, or either lateral position. At least two exposures should be made, one in the antero-posterior and the other in the lateral direction. Since the fetus is nearer the film in the prone position, this is the better of the antero-posterior projections. For this exposure, if the pregnancy is advanced and the abdomen large, pillows may be placed under the thighs and the patient may support the upper part of the body on her elbows. Routinely, we make an exposure in the prone and right lateral positions (Fig. 158).

For exposures early in pregnancy, the abdomen below the umbilicus should be shown on the films. For this the 11- by 14- or 14- by 17-inch films are necessary. For those late in pregnancy, the 14- by 17-inch films should be used.

THE EXAMINATION OF DISCHARGING SINUSES.

Patients who have had gall bladder and other drainage operations and those who have suppurative disease around the rectum, in the groin, extending down the psoas muscles from the vertebræ or perirenal tissues, or coming from bones, occasionally have persistent discharging sinuses. It is important that the origin, direction, and extent of these be determined before operative measures for their permanent cure are undertaken. By examining these sinuses filled with radiopaque substances, this information can be obtained by the roentgenologist for his surgical colleagues.

Various preparations have been used for this purpose, the opacity to Roentgen-rays of all of them being produced by barium sulphate, bismuth, iodine, or bromine in some form contained in them. Beck's bismuth paste is probably the oldest and best known of such preparations. Schanz describes three preparations containing sodium bromide or iodide in a mixture containing either corn starch, Irish moss, or tragacanth and glycerin, with 0.5 per cent phenol added as a preservative. MacLeod recommends an emulsion of 1 part of oxychloride of bismuth and 2 parts mucilage of acacia. A useful liquid preparation of sodium iodide consists of a 12 per cent solution containing mercuric iodide in a strength of 1 to 3000 to render the solution sterile and mildly antiseptic. More recently the iodized oil preparations such as lipiodol and iodopin have been introduced.

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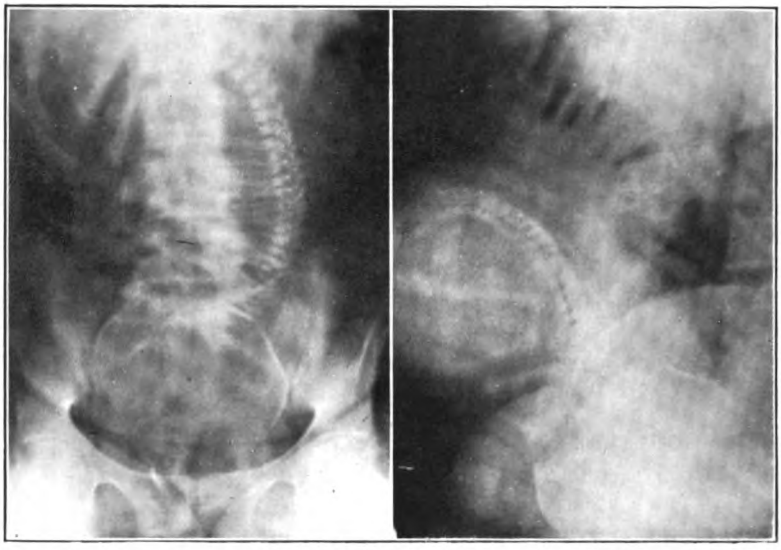

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Patients who have had gall bladder and other drainage operations and those who have suppurative disease around the rectum, in the groin, extending down the psoas muscles from the vertebræ or perirenal tissues, or coming from bones, occasionally have persistent discharging sinuses. It is important that the origin, direction, and extent of these be determined before operative measures for their permanent cure are undertaken. By examining these sinuses filled with radiopaque substances, this information can be obtained by the roentgenologist for his surgical colleagues.

Various preparations have been used for this purpose, the opacity to Roentgen-rays of all of them being produced by barium sulphate, bismuth, iodine, or bromine in some form contained in them. Beck's bismuth paste is probably the oldest and best known of such preparations. Schanz describes three preparations containing sodium bromide or iodide in a mixture containing either corn starch, Irish moss, or tragacanth and glycerin, with 0.5 per cent phenol added as a preservative. MacLeod recommends an emulsion of 1 part of oxychloride of bismuth and 2 parts mucilage of acacia. A useful liquid preparation of sodium iodide consists of a 12 per cent solution containing mercuric iodide in a strength of 1 to 3000 to render the solution sterile and mildly antiseptic. More recently the iodized oil preparations such as lipiodol and iodopin have been introduced.

Beck's paste must be injected while heated, it does not mix with pus or tissue débris, it cannot be washed out of sinus tracts or cavities, often being retained for weeks, and in earlier days cases of poisoning from it were reported. Its retention makes it possible to make examinations in more than one position without danger of its running out. Since it has distinct antiseptic properties and is used in treatment, its particular field of usefulness is in injecting sinuses springing from bones and joints. The preparations described by Schanz and MacLeod are of such consistency that they are well retained during the examinations and, being water soluble, they can be washed out by irrigating with saline solution. The sodium iodide solution is most useful in pyelography and in injecting sinuses springing from the viscera, for example one connected with the gall bladder and biliary tract. It has the disadvantage of running out of the sinus when the position of the patient is changed, so that if the opening cannot be closed, all exposures must be made with it uppermost. The iodized oils have the same objections as the iodide solution, and in addition are too expensive for the injection of any but small sinuses or spaces.

The method of preparation of bismuth paste as given by Beck is as follows:

"Bismuth paste is a 10 per cent mixture, 1 part of bismuth subnitrate to 9 parts of vaseline. The mixing bowls, jars, and spoon are sterilized. The vaseline is sterilized by heating for twenty minutes if not in the original container. The bismuth subnitrate is sterile in sealed cans when it comes from the manufacturer and so does not have to be resterilized. The mixing bowls and jars must be absolutely dry, as the slightest amount of water produces a curdling of the paste and it is then useless.

"The bismuth subnitrate is poured into the mixing bowl and all lumps smoothed out with the spoon. Sufficient amount of vaseline, which is still in the liquid condition from the sterilizing, is poured slowly into the bismuth, to make a stiff paste. This mixture is then stirred for an hour until it is a smooth, bright yellow, homogeneous paste.

"To the balance of the nine parts of the liquefied vaseline which has been heated to liquefaction, this mixture of thick paste is gradually added, stirring it constantly. The resulting product should be a light yellow, smooth, homogeneous paste, which, on cooling, becomes congealed without the precipitation of the bismuth."

The corn starch preparation described by Schanz is made by

suspending 10 grams of corn starch in 100 cubic centimeters of water and heating in a water-bath. It is stirred continuously until a thick paste is formed. Sixteen cubic centimeters of glycerin are then mixed in thoroughly. Then either 15 grams of sodium iodide or 25 grams of sodium bromide are added. To preserve the preparation, 0.5 cubic centimeter of phenol or 1 cubic centimeter of oil of thyme is added.

The technique of injecting a discharging sinus is the same with any preparation that is used. If Beck's paste is used, it is first melted in a water-bath and well stirred with a glass rod that has been flamed.

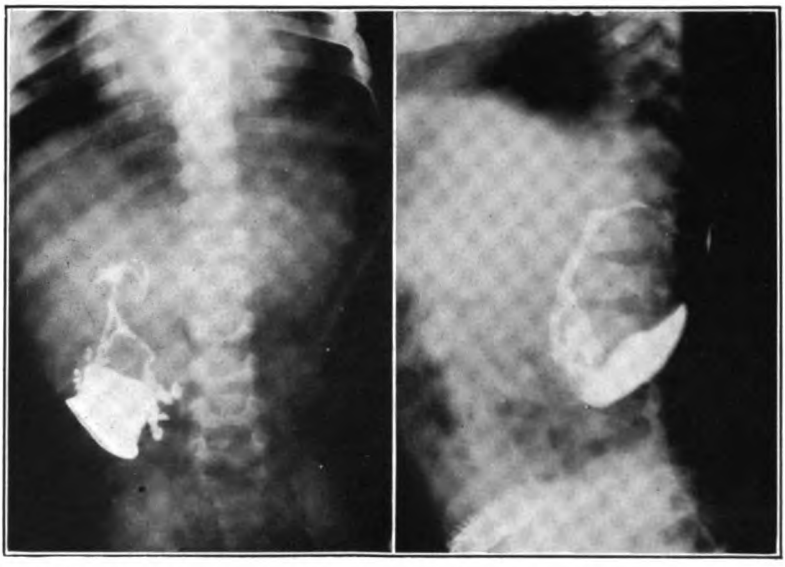

FIG. 159.—An antero-posterior and a right lateral view of an injected sinus tract in a child, originating in the perirenal tissues.

The syringe is boiled and must still be quite warm. Other preparations also should be warm when injected. The preparation is drawn into a 10- or 20-cubic centimeter glass syringe, the tip for attaching the needle is introduced into the opening of the sinus, and the injection slowly made. Because pressure can be made with the end of the syringe around the opening to prevent reflux of the material, a syringe without a cannula or needle usually is satisfactory. If there are more openings than one, these must be closed with the fingers as the preparation begins to escape from them. The

injection is continued until the patient begins to complain of pressure. When the injection has been completed, the syringe is removed, the excess of the preparation wiped from the skin, and, if possible, all openings closed with strips of adhesive plaster to which have been fastened small pieces of lead so that the position of the openings will be shown on the films.

The roentgenography does not differ from that of the same part of the body for any other purpose. If the direction and extent of the sinus is unknown, it is advisable to use rather large films and include a considerable distance both above and below the openings. Whenever possible, stereoscopic films should be taken. If they are not made, two views, at right angles to each other, should be made (Fig. 159). For parts of the trunk or region of the hips a Potter-Bucky diaphragm is essential.

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